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STUDY OF EFFICIENCY AND CURRENT USE OF RESPIRATORY PROTECTIVE DEVICES

by

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STUDY OF EFFICIENCY AND CURRENT USE OF RESPIRATORY PROTECTIVE DEVICES

ABSTRACT

The efficiency of a helmet-type powered air-purifying respirator was studied in the work environment of an underground uranium mine. Workplace protection factors (WPF) were measured, using approximately 30-minute air sampling periods and repeated sampling throughout the work shifts for six miners during three shifts each. The WPF of the modified Racal AH-5 helmet was 17.8 (geometric mean) with new filters in the respirator; the WPF dropped to 5.3 when four-day-old filters were used. The WPF results were lognormally distributed. The test population appeared to be a homogeneous set: there was no significant difference in the mean WPFs of individual test subjects. The study could not resolve any effect of elapsed time within the work shift or of ambient Working Level on the WPF.

The actual use levels and the problems associated with respirator use were studied at the same time, principally via a user survey. The respirators have a high level of acceptance among the user population of underground uranium miners and 72.5% of the 207 survey respondents stated six or more hours use with the visor in the correct "down" position per shift.

RÉSUMÉ

Le présent rapport fait état de l'efficacité d'un masque de type casque avec purificateur d'air autonome dans le milieu de travail d'une mine souterraine d'uranium. On a mesuré les facteurs de protection en milieu de travail (WPF) en suivant six mineurs pendant trois de leurs quarts de travail et en prélevant des échantillonnages d'air pendant 30 minutes tout au long de leur journée de travail. Le facteur WPF du casque Racal AH-5 modifié était de 17,8 (moyenne géométrique) lorsqu'il était muni de filtres neufs, mais il a diminué à 5,3 lorsque les filtres avaient servi pendant quatre jours. La distribution logarithmique des WPF avait la forme gaussienne. Le groupe des sujets étudiés semblait représenter un groupe homogène : il n'y avait pas de différence importante entre les moyennes individuelles des WPF. L'étude n'a pas été en mesure de déceler le moindre effet sur le WPF qui soit relié au temps écoulé pendant le quart ou à l'unité alpha (WL) ambiante.

On a étudié en même temps le niveau réel d'utilisation et les problèmes reliés à l'utilisation du masque, surtout en menant une enquête auprès des utilisateurs. Le pourcentage des mineurs qui ont accepté le masque est élevé puisque 72,5 % des 207 mineurs qui ont répondu à l'enquête ont affirmé qu'ils utilisaient leur masque correctement avec la visière abaissée, au moins six heures par quart.

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Page

3. RESPIRATOR USAGE..... 19

3.1 General..... 19

3.2 Results..... 22

4. MODEL AH-3 WORKPLACE PROTECTION FACTORS..... 25

4.1 General..... 25

4.2 Measurements and Observations..... 25

5. EFFECTIVE AND ASSIGNED PROTECTION FACTORS..... 28

6. SUMMARY AND CONCLUSIONS..... 30

6.1 General..... 30

6.2 Efficiencies..... 31

6.3 Respirator Usage..... 31

6.4 Protection Factors..... 32

TABLES..... 33

REFERENCES..... 78

APPENDICES:

TRANSFORMATION OF NORMALIZED COUNTS..... APPENDIX A

RESPIRATOR SURVEY..... APPENDIX B

TABLE OF CONTENTS

	Page
List of Tables	iv
List of Figures	vi
Acknowledgments	vii
SUMMARY AND RECOMMENDATIONS	1
1. INTRODUCTION	4
1.1 Background and Objectives	4
1.2 Study Design	5
2. RESPIRATOR EFFICIENCIES	6
2.1 Measurement Requirements	6
2.2 WPF Measurement Protocol	7
2.2.1 Radon Daughter Activity Measurements	7
2.2.2 Air Exit Velocities	7
2.2.3 Respirator Filters	7
2.2.4 Test Subjects	8
2.2.5 Respirators	8
2.3 Experimental	8
2.3.1 Sampling Methods	8
2.3.2 Alpha Activity Measurements	9
2.3.3 Air Velocity Measurements	9
2.3.4 Logistics	10
2.4 Results	11
2.4.1 Data Reduction	11
2.4.2 Measurements and Observations	13
2.5 Analysis	14
2.5.1 General	14
2.5.2 WPF Distributions and Mean Values	14
2.5.3 Analysis of Variance	16
2.5.4 Working Level Ratios	18

Table		Page
2-23	Calculated Radon Daughter Concentrations and Working Levels - Subject F - New Filters	55
2-24	Calculated Radon Daughter Concentrations and Working Levels - Subject F - Old Filters	56
2-25	Calculated Radon Daughter Concentrations and Working Levels - Subject G - Old Filters	57
2-26	Test Subject Work Activities	58
2-27	Respirator Air Exit Velocities	59
2-28	Workplace Protection Factor Distributions	60
2-29	Summary of WPF Analysis of Variance	61
2-30	Regression Coefficients of Transformed and Untransformed WPFs with V_E	62
3-1	Months of Experience With Respirator	63
3-2	Survey Response by Job Classification	64
3-3	Rating of Comfort	65
3-4	Visibility Rating	66
3-5	Work Activities Where Airstream Problems Encountered	67
3-6	Respirator Failed In Use	68
3-7	Types of Respirator Failures	69
3-8	Changes in Airflow Noticed During Shift	70
3-9	Lifts Visor When Talking	71
3-10	Travels With Visor Up or Down	72
3-11	Hours of Shift With Visor Down	73
3-12	Summary of Comments	74
4-1	Summary of Start of Shift/End of Shift/End of Shift AH-3 Peripheral Air Velocities	75
4-2	Summary of AH-3 Test Results for Subject A	76
4-3	Calculated Radon Daughter Concentrations and Working Levels (Subject A - AH-3)	77

List of Tables

Table		Page
2-1	Test Subject Job Classification	33
2-2	Summary of AH-5* Test Results for Subject A - New Filters	34
2-3	Summary of AH-5* Test Results for Subject A - Old Filters	35
2-4	Summary of AH-5* Test Results for Subject B - New Filters	36
2-5	Summary of AH-5* Test Results for Subject B - Old Filters	37
2-6	Summary of AH-5* Test Results for Subject C - New Filters	38
2-7	Summary of AH-5* Test Results for Subject C - Old Filters	39
2-8	Summary of AH-5* Test Results for Subject D - New Filters	40
2-9	Summary of AH-5* Test Results for Subject D - Old Filters	41
2-10	Summary of AH-5* Test Results for Subject E - New Filters	42
2-11	Summary of AH-5* Test Results for Subject F - New Filters	43
2-12	Summary of AH-5* Test Results for Subject F - Old Filters	44
2-13	Summary of AH-5* Test Results for Subject G - Old Filters	45
2-14	Calculated Radon Daughter Concentrations and Working Levels - Subject A - New Filters	46
2-15	Calculated Radon Daughter Concentrations and Working Levels - Subject A - Old Filters	47
2-16	Calculated Radon Daughter Concentrations and Working Levels - Subject B - New Filters	48
2-17	Calculated Radon Daughter Concentrations and Working Levels - Subject B - Old Filters	49
2-18	Calculated Radon Daughter Concentrations and Working Levels - Subject C - New Filters	50
2-19	Calculated Radon Daughter Concentrations and Working Levels - Subject C - Old Filters	51
2-20	Calculated Radon Daughter Concentrations and Working Levels - Subject D - New Filters	52
2-21	Calculated Radon Daughter Concentrations and Working Levels - Subject D - Old Filters	53
2-22	Calculated Radon Daughter Concentrations and Working Levels - Subject E - New Filters	54

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List of Figures

		Page
Figure 1:	Modified Racal Airstream AH-5 Helmet (AH-5*).....	3
Figure 2:	Locations For Air Velocity Measurements.....	10
Figure 3:	Workplace Protection Factor Distributions for the AH-5* PAPR..	15
Figure 4:	Scattergram of Pseudo Activity Concentrations (Cp) and Working Levels (WL) (Inside).....	20
Figure 5:	Scattergram of Pseudo Activity Concentrations (Cp) and Working Levels (WL) (Outside).....	21
Figure 6:	Distribution of AH-5* Usage During Shift.....	23
Figure 7:	Racal Airstream AH-3 Helmet.....	26
Figure 8:	Effective Protection Factors for the AH-5* in Underground Uranium Mining Environments.....	29

STUDY OF EFFICIENCY AND CURRENT USE OF RESPIRATORY PROTECTIVE DEVICES

SUMMARY AND RECOMMENDATIONS

Helmet type powered air-purifying respirators (PAPR) are used voluntarily on a continuous basis by several hundred underground uranium miners in Canada. This use has the potential for the reduction of radon-thoron daughter exposures and the present study attempts to quantify the protection being provided by respirator use, in particular by the use of (user-modified) Racal Airstream AH-5 Airstream helmets at a large underground uranium mining operation.

To make sure that respirator efficiencies determined will be of practical value, the study was designed to measure the efficiences in the mine, in the course of real-life work activities of actual users, who represent a cross-section of miners' job classifications and work activities.

Eighty-nine Workplace Protection Factor (WPF) measurements were collected in a variety of work locations by monitoring seven different miners, throughout a total of 18 workshifts, engaged in a wide range of activities (pipefitter, electrician, leaching attendant, jumbo driller, conveyor operator, and two scoop tram operators). Measurements were considered valid only if the respirator was used properly during the half-hour sampling periods.

The measurements consisted of sampling the air both inside and outside the respirator and counting the collected alpha activity. The WPF was taken to be the ratio of ambient activity to inhaled activity. The values were in agreement with the corresponding ratios of radon daughter Working Levels and they describe the protection regardless of the nature of activity in the air, be it radon daughters, thoron daughters or uranium. Workplace protection factors were found to be lognormally distributed, and for AH-5* respirators equipped with new filters the WPF distribution had a geometric mean of 17.8 and a geometric standard deviation of 1.84. When randomly selected used filters (four shift prior use) were installed in the respirators the WPFs dropped significantly (geometric mean 5.3 and geometric standard deviation 1.79).

The WPF distributions obtained are considered to be representative and suitable to describe the protection of the whole user population, provided tasks and conditions are normal or usual. They may be used to determine Assigned Protection Factors (APF) which describe the protection guaranteed to a large proportion of the users during proper use. If this proportion is taken as 90%, the APF_{90} values are 8.2 and 2.5, respectively, for new and 4-day old used filters.

A survey of regular AH-5* users indicates a median use of 6.25 hours per shift with the respirator visor down. This value, which is based on the subjective estimates of more than two hundred miners from most underground occupational groups, corresponds to proper usage during 83% of the workshift. Ninety-three percent of the respondents stated proper use during at least 4 hours per shift.

Proper use of the respirator is the dominant factor in the overall protection achieved in the course of a complete workshift by a miner. This overall protection is quantified by Effective Protection Factors (EPF) which take into account the periods of non-use as well as the protection achieved during use. For a 6 hour per shift user the EPF is 4.1 and 2.8 respectively, for new and 4-day old used filters.

AH-5* - designates the standard AH-5 adapted to operate from a miner's cap lamp battery.

To guarantee to 90% of the users an EPF of 2, which is equal to the dose credit presently applied, proper use with the visor down is required during 4 hours with new filters in the respirator and during 6 hours with 4-day old used ones.

The principal recommendation arising from this study is a general one:

1. The most efficient way to improve protection is by increasing proper use with the visor down among the miners.

More specific recommendations oriented in the same direction are:

2. Improvements to the respirators used in underground mining should aim to increase the acceptance of the devices and to reduce the inconveniences of their use. Options such as chin straps, ear protectors and different visor seals should be made available to the users.

3. Users should be encouraged to wear the PAPR with the visor down. They should be informed of the protection which can be achieved with the visor down and of the effect the proportion of the time the visor is worn correctly has on overall protection.

4. Program administration should attempt to ensure that most users have the visor down during at least 4 hours of the shift.

5. Respirator use patterns can change. In programs using a dose credit system, use levels should be regularly assessed.

6. Enabling the user to communicate clearly with the visor down, which may be difficult to achieve, would have a significant impact on proper use.

Other equipment and efficiency-related recommendations are:

7. Any decisions regarding filter reuse or higher efficiency respirators should include a full consideration of the prevailing usage pattern.

8. The use of the cap-lamp batteries to power the respirators did not appear to result in a decrease in operating performance during the WPF measurement study. However, a survey of the majority of the respirator users indicates that cap-lamp intensity and respirator airflow may decrease towards the end of the shift. The extent of performance changes should be examined and the cause identified with a view to set an acceptance level for the performance of batteries serving as a power source for both workplace illumination and respiratory protection.

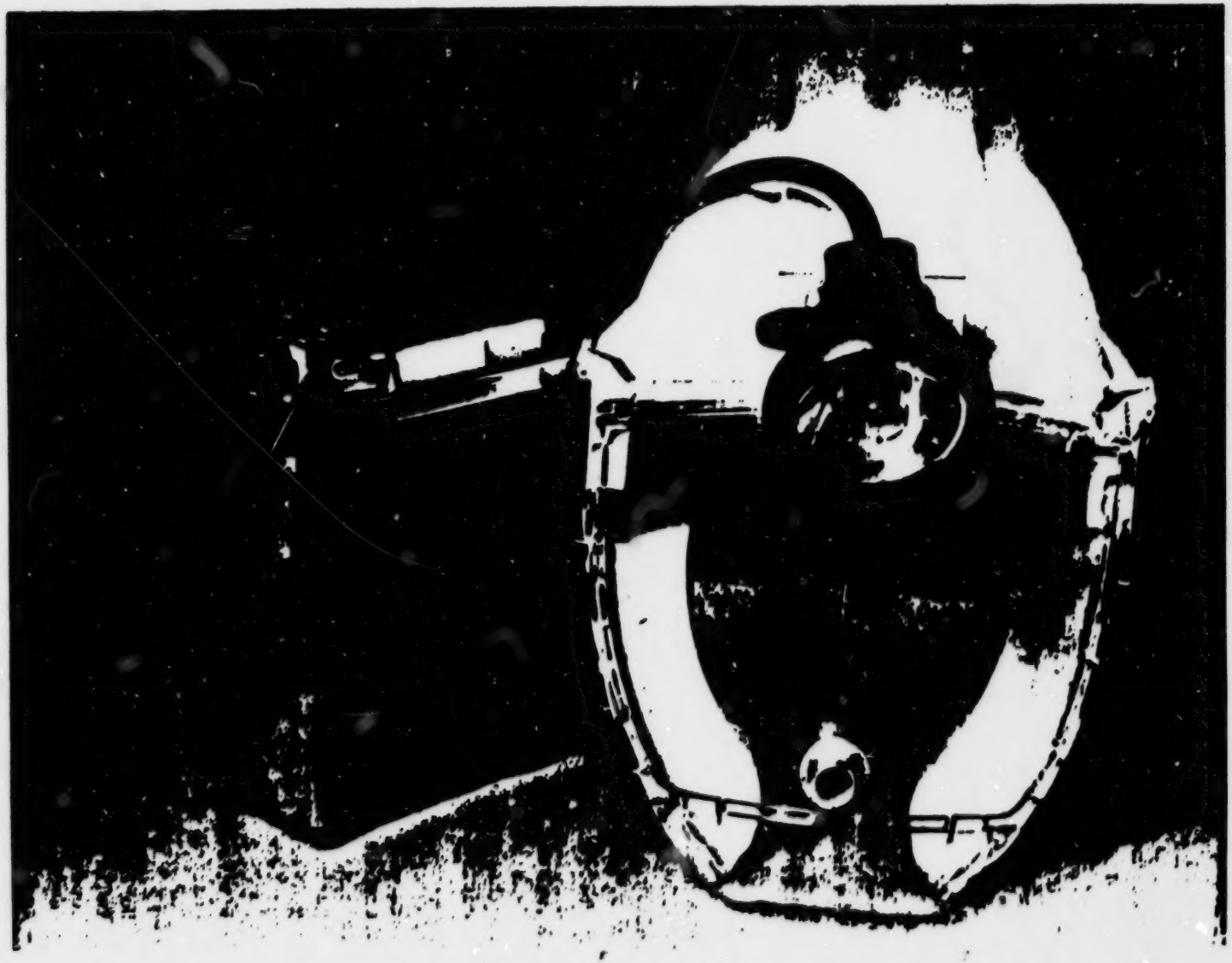

FIGURE 1: Modified Racal Airstream AH-5 Helmet (AH-5*)

1. INTRODUCTION

1.1 Background and Objectives

Occasionally respirators are used in underground uranium mining for protection against occurrences of high levels of dust, smoke and radon daughters. However, only recently with the development of user-acceptable Powered Air-Purifying respirators (PAPR)[1], have many of the problems[2] associated with underground respirator use been, at least partially, circumvented. In the past, attempts at using respirators, particularly negative pressure devices, often proved less than satisfactory, largely due to the physiological stress imposed on miners in overcoming the resistance to breathing created by the filters. Early PAPRs, while eliminating the breathing resistance problems, were usually heavy and cumbersome, or required hoseline connections to the source of respirable air, limiting the mobility of the miner. Lightweight self-contained PAPRs, originally developed during the 1970's in the UK, have gained considerable user acceptance, which have resulted in miners wearing PAPRs on a voluntary basis for significant periods during the workshift rather than wearing negative pressure air-purifying respirators, even though mandatory use may be required for only brief periods.

As a consequence of voluntary respirator use in excess of periods prescribed by employers, a potential exists for a significant reduction in exposures to radon daughter activity. The actual level of protection achieved will depend on the efficiency of the filter for removing radon daughter activity, on the fraction of respired air bypassing the filter, as well as on the condition of the equipment and the wearer's habits in the use of the respirator.

This study examines the protection provided by one type of PAPR which is used extensively in the Canadian uranium mining industry. A preliminary examination of the performance of the same PAPR equipped with a high efficiency air purification system was also performed.

Respirator efficiencies are usually defined in terms of contaminant concentrations which exist inside and outside the respirator (efficiency = 1 - Ci/Co), where the ratio Co/Ci is commonly referred to as a Protection Factor (PF). Because this ratio can be determined from a variety of techniques based on experimental methods, or a combination of experimental and theoretical methods, any discussion of respirator efficiencies requires explicit definition of PFs. Four terms are used in this report to describe respirator efficiencies[3]:

- Fit Factors (FF), which are quantitative measures of Co/Ci for an individual wearing the respirator in a test chamber containing a test aerosol (normally DOP or NaCl) of known particle size and size distribution;

- Workplace Protection Factors (WPF) are a measure of the ratio Co/Ci for individuals wearing and using respirators properly under actual working conditions;

- Assigned Protection Factors (APF), which are derived quantities representing the minimum anticipated workplace protection factor that would be provided by a properly functioning respirator to a specified proportion (usually >90%) of properly trained users. The value is derived from a representative set of workplace protection factor measurements;

- Program Protection Factors (PPF), which are values representing the protection provided by a respirator in a specific respirator program. The PPF is affected by all aspects of the respirator program (i.e. selection, maintenance, work environment, work activities, training, program administration - in addition to WPF and proper use) and by any deficiencies in them.

This study measured WPFs and APFs for the Racal Airstream AH-5* PAPR when used in a uranium mine for protection against radon daughter activity. This information, when combined with usage-related data, provides a basis for estimating the PPF. Currently the respirator is considered to provide a PPF of 2 for radon daughters in Canadian underground uranium mining and credits based on the PPF are applied to Working Level (WL) exposures of miners using the device.

This work, which was supported by the Atomic Energy Control Board of Canada, was established to examine the performance of AH-5* in a large underground uranium mine in Ontario, Canada. The specific objectives were to:

- measure the efficiency of the AH-5* under actual conditions in a mine;

- make preliminary WPF measurements on the Racal Airstream AH-3 PAPR (high efficiency model of the Airstream respirator) and recommend a suitable protocol for representative WPF measurements;

- evaluate the current level of use of the AH-5* in terms of the employer's instructions, and the recommendations of the device manufacturer;

- identify problems associated with wearing and using the respirators;

- recommend improvements in device design and use where required.

1.2 Study Design

The performance of respirators has been measured in several industries under actual working conditions. However, the protocols used to make these measurements have varied considerably. Que Hee and Lawrence[4], in measurements on the AH-3 PAPR as used by brass foundry workers, established the likely range of efficiencies which may be realized, but because of few controls over actual respirator use patterns (lifting of the visor in particular) the applicability of the measurements in establishing reliable APFs and PPFs is limited. Myers et al[5] followed a strict protocol for both the condition of the PAPR and the use of the device during the tests, thus their study represents optimum conditions (respirator supplied by study organizers and maintained by manufacturer-trained personnel; respirator adjustments were made either by the study researchers or under their supervision). Underlying any respirator efficiency study is the objective of identifying the long-term protection provided through respirator use within an actual respirator program. In order that this study, and the results obtained, be applicable to real programs encountered in underground uranium mining the protocol designed for the efficiency measurements was neither excessively strict nor lacking controls that ensure valid WPF measurements.

Unlike negative pressure air purifying respirators, whose actual performance can vary appreciably due to facial hair, face shape and size and proper fitting even among trained users, the overall protection provided by helmet type PAPRs like the AH-5 is most likely affected by lifting the visor during use. The proportion of time the visor is worn in the "up" position (no protection) and in the "down" position (proper use) becomes a practical index for the level of protection achieved with a PAPR and has the greatest impact on the establishment of a PPF. In order to obtain an indication of the range of PPFs that can be realized in underground uranium mining more than two hundred AH-5* respirator users were surveyed to assess their respirator use patterns and the factors which affect these patterns.

2. RESPIRATOR EFFICIENCIES

2.1 Measurement Requirements

Measurements of workplace protection factors were achieved by measuring radon daughter activity collected on filters sampling particulates in the air inside and outside the respirator during use. The sampling protocol and techniques utilized were influenced by the actual efficiency of the respirator; the environmental conditions in the workplace; the work schedule of the test subjects; the general operations within the mine; as well as the need to obtain representative WPF measurements. The following general conditions for obtaining representative WFP measurements for individuals as well as AH-5* users as a group were identified:

1. The individual WPF measurements should be made by using extended sampling periods. Recent workplace protection factor measurements[6] for some Airstream respirators indicate that very little correlation exists between FFs obtained in the laboratory (<5 minute sampling) and WPFs observed in the workplace (4-8 hour periods). Even though there are several factors that may contribute to the differences, it is certain that short sampling periods would not be representative of the range of environmental conditions, work activities and breathing rates that may prevail in the workplace. In addition, the total impact of the ingress of contaminated air into the breathing zone and by-passing the filter may not be adequately identified by short sampling periods.

2. The sampling should be performed through the complete workshift in order to observe any effects on the performance of the respirator caused by diminished airflow due to filter loading and decreasing battery voltage, or by increased filter efficiency due to filter loading.

3. The participating miners should represent a broad cross section of AH-5* users and should perform during the tests their routine work in their normal work environments. The number of test subjects utilized and the number of samples obtained for each individual should be sufficiently large to achieve a fair representation of the general conditions of the workplace.

4. The respirator should be in proper working order.

5. The respirator should be worn properly, meaning in particular that the visor should be in the "down" position throughout sampling periods.

Limitations that existed in meeting some of these conditions completely are discussed in subsequent sections.

2.2 WPF Measurement Protocol

2.2.1 Radon Daughter Activity Measurements

A number of techniques[7] are available for measuring radon daughter concentrations and working levels (WL) in mine atmospheres. Though these techniques have proven reliable for monitoring environmental conditions in the workplace, each presents a problem when respirator WPF measurements are required.

The standard Kusnetz method is not sufficiently sensitive[8], particularly for measuring the WL inside the respirator. In addition, it can not accommodate long sampling periods, and this same limitation prevents also the use of the more sensitive Modified Kusnetz method.

Both the Rolle and the various versions of the Tsivoglou method allow for long sampling periods but they are accurate only if radon daughter concentrations do not change appreciably during the sampling. Thus the need to utilize extended sampling periods introduces problems associated with temporal and spacial variations in radon daughter concentrations. The methods have proven adequate for environmental monitoring with static samplers where there are only slow temporal variations to contend with. However, spacial variations in radon daughter concentrations likely encountered by test subjects, particularly those moving extensively throughout the mine during the course of their work, may seriously affect the accuracy of radon daughter concentration and working level results.

Because of the flexibility offered by the modified Tsivoglou technique, the count intervals of 2-5, 6-20 and 21-30 minutes were used for measuring alpha activity on the sampling filters, even though an analysis of the alpha counts by this method could not be expected to always provide acceptable information on radon daughter composition and working levels.

Rather than introducing errors due to the inadequacy of the steady concentration model implicit in the Tsivoglou method, the workplace protection factors were calculated as the ratio of the integrated (2-30 minutes) alpha activities* on the filters of the "outside" and "inside" sampling train.

2.2.2 Air Exit Velocities

To establish whether the performance of the respirator changed appreciably during the shift, measurements of the air exit velocities were made at the exhaust port in the AH-5* faceshield at the beginning of the shift as well as (in some cases) at the end of the shift. The purpose of these measurements was to obtain an indication of any abnormal leakage or fan performance.

2.2.3 Respirator Filters

According to the manufacturer's instructions a properly operating PAPR's performance is satisfactory until the airflow test fails. Experience with the AH-5 PAPR indicates that on many occasions the main filter

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* "normalized counts" as described in 2.4.1

can be reused for several shifts before filter loading and the resultant pressure drop cause a failure in the manufacturer's airflow test. To determine the effects of "OLD" filters, WPFs were measured with

1) new filters installed in the PAPR at the onset of the shift

2) respirators having filters installed which had been used for four previous shifts. The used filters were selected at random.

Test subjects were sampled for two shifts with "NEW" filters installed in their respirators and one shift with four-day-old filters ("OLD").

2.2.4 Test Subjects

Miners participating in the study were selected on the basis of availability (volunteers) and job classification. The various underground mining occupations were grouped into six categories and two subjects were selected from each category, one being designated as an alternate. The subjects and the occupational groups they represent are listed in Table 2-1. Subject G was used as an alternate when the original participant E and the designated alternate were unavailable for testing.

2.2.5 Respirators

A condition of representative WPF measurements is that the respirator be properly functioning. In this study the test subjects used respirators that had been issued to them by the employer and maintained by the respirator service department within the company. Observations of the respirator maintenance procedures indicated that the respirators were maintained according to the manufacturer's instructions, consequently respirators external to the program were not utilized.

2.3 Experimental

2.3.1 Sampling Methods

Separate sampling systems were used for sampling the air inside and outside the respirator. Each system consisted of a personal air-sampling pump operating at approximately 2 L/min, and a Delrin Model 1109 in-line filter cassette containing a Whatman GF/A glass fibre filter paper. The two air-sampling pumps were attached to the miner's safety belt, with 6 mm tygon tubing leading to the appropriate filter cassette. Sampler pump flows were examined prior to each shift to ensure the satisfactory operation of the pump and maintenance of the pump calibration.

The exterior sampling cassette was placed near the top of the AH-5* helmet rather than in the more conventional lapel position. This was done to avoid aspiring the exhausted air from the PAPR or resuspended activity from the miners' clothes.

A sampling probe inserted through a 0.5 cm hole in the faceshied visor, approximately in line with the upper lip of the test subject, was used to sample the interior of the respirator. It extended about 1 cm into the interior. The filter cassette was attached directly to the probe fixed in the visor and a specially fabricated quick-disconnect fitting was used to attach the tygon tubing to the filter cassette.

Two potential sources of error not normally encountered in personal monitoring required consideration in the WPF measurements:

Sampling of expired air denuded of particles due to deposition within the respiratory system could result in WPFs that are too high. The errors due to sampling some exhaled breath were considered small, because volumetric flow rates produced by the respirator (> 170 L/min) were much higher than respiratory minute volumes[9].

The error due to particle losses in the sampling probe was also considered small. Significant deposition of particles greater than 5 μm in size can occur in short probes, particularly in ones perpendicular to the airflow[10]. However, the deposition of radon daughter particules in the probe employed is deemed negligible in view of the flowrates employed and of the particle size being less than 1 μm[11, 12].

2.3.2 Alpha Activity Measurements

Alpha activity collected on the "inside" and "outside" filter papers was counted with AECL Model AEP 5236A portable alpha monitors, which have surface barrier detectors. Detector outputs were recorded on Nuclear Enterprises PSR-8 scaler/ratemeters. Detectors and sample holders were assigned exclusively to "inside" or "outside" functions in order to avoid cross-contamination. Digital stopwatches were used to time the counting intervals.

Detector efficiency calibration checks were made regularly throughout the study. Near-contact point source efficiencies, obtained with a ^{241}Am calibration source, ranged from 37% to 41% for all the detectors used. Individual efficiency measurements did not differ by more than 3% from the mean value.

The WPF measurements as well as the proper use of Tsivoglou's equations required that detector efficiencies be identical for RaA and RaC' alphas. This was verified using a Pylon model RN-290 radon daughter calibration source. No significant difference in the detector efficiencies was observed during the decay of the source. The source also provided a means of comparing point source and filter-paper counting geometries. Measurements made with several AEP 5236 type detectors showed that the 2π efficiency for the filterpaper (extended source) counting geometry was approximately 27% (compared to 40% for a point source).

2.3.3 Air Velocity Measurements

A Datametrics 800 VTP hot-wire anemometer was used to measure the velocity of the air exhausted by the respirator at the chin port in the faceshield. The position of the measurement points is illustrated in Figure 2.

All measurements were made above ground either before the shift or at the completion of the shift, as the likelihood of finding a convenient draft-free place underground was remote.

2.3.4 Logistics

At the beginning of each shift miner participants were met by study staff members on "surface" where the sampling devices were attached to the miners' own equipment and the respirator was briefly inspected. When time permitted, air velocity measurements were obtained. The test subjects were accompanied underground, their work schedules for the shift identified and a schedule for

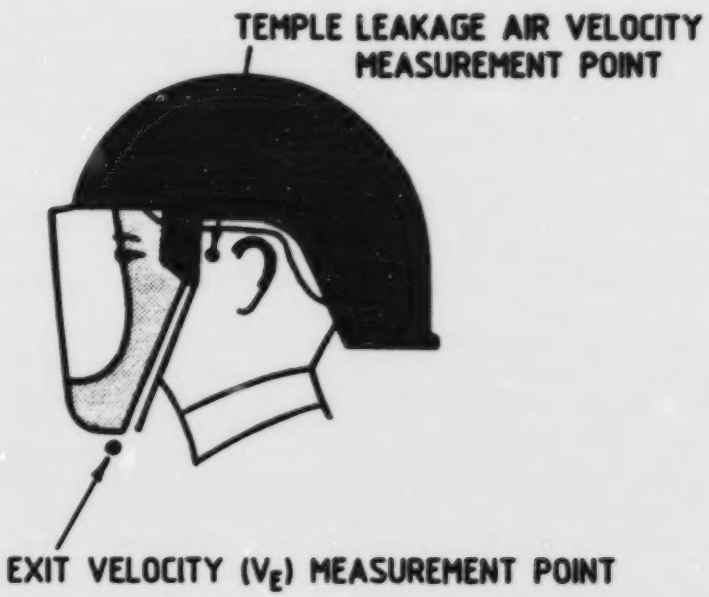

FIGURE 2: Locations for Air Velocity Measurements

sampling was established. Sampling was initiated as soon as possible after going underground, but samples could rarely be collected during the last two hours of the shift because of logistics requirements in moving people and equipment to the surface.

Whenever possible 30 minute sampling periods were used, but a strict adherence to this value was not always practical or necessary for the reduction of the data. The sampling periods ranged from 18 to 60 minutes, but most of the values were close to the mean value of 31 minutes.

At the completion of the shift, air velocity measurements were repeated for some of the participants when their schedules permitted it.

2.4 Results

2.4.1 Data Reduction

Alpha count data obtained from the measurement of filter samples representing the "inside" and "outside" activity concentrations were "normalized" by dividing the recorded gross alpha count (A) by the product of the detector efficiency (ε) and the sampling rate (Q in L/min); i.e. $N = A/\varepsilon Q$.

The pump flow rates used in the calculations were usually determined from the total integrated flow indicated by the revolution counters fitted to the sampling pumps. However, on several occasions the mechanical flow counter failed or recorded incorrectly. In these cases pump flows were based on the free-flow flowrate calibration of the pump. The free-flow rates were multiplied with 0.80, which was the average ratio between rates from acceptable flow counter data and free-flow calibrations. (All sampling pumps were of the same model.)

The availability of triplicate counts for each filter permitted checking for consistency between the counts obtained in the different counting intervals. This was done by invoking that activity on the filter could not decay faster than pure RaA; neither could it grow in faster than from (hypothetical) pure RaB on the filter. These were the least restrictive conditions on activity ratios, any alpha activity originating from either RaC', thoron daughters or from longer-lived isotopes would fall within the RaA and RaB limits. Computer simulations of sampling either pure RaA or pure RaB for 15 seconds resulted in the following bounds:

$$1.03 < N_{6,\ 20}/N_{2,\ 5} < 12.31$$

$$1.14 < N_{6,\ 20}/N_{21,\ 30} < 3.33$$

$$0.31 < N_{21,\ 30}/N_{2,\ 5} < 10.84$$

where the subscripts of the normalized counts N indicate the beginning and end of the counting intervals.

Eighteen counts, all of them on "inside" filters, were rejected because the count ratios did not conform to the bounds given above. These counts are carried in the data tables but are marked as invalid. Their rejection, though preventing the calculations of concentrations and working levels, did not interfere with determining the WPF.

The reason for the bad counts was most likely some fault in the detector-cable-scaler assembly dedicated to counting "inside" activities. The overall frequency of the occurrence was one per 2 hours of counting time and the distribution of bad counts among the count intervals (2 in first, 11 in second, 5 in third) mirrors the duration of the intervals. Reading errors are not a likely cause, especially because no bad counts were identified on "outside" filters.

The ratio of "outside" to "inside" total normalized counts was taken to be the Workplace Protection Factor ($WPF = N_{outs}/N_{ins}$). If a reading from a count interval was missing (due to a missed value at the time of measurement or the deletion of an invalid data point) then the WPF was taken to be the outside/inside ratio of the normalized counts summed over the remaining count intervals.

Two WPF outliers were rejected on the basis of combined statistical and practical considerations:

-(Subject E/New Filter/840301/1255)

The WPF value of 292 obtained was more than 7 standard deviations from the mean. Although the proper functioning of the pumps was verified in the field it is conceivable that some part of the inside sampling train became disconnected or clamped. All "inside" counts were rejected.

-(Subject E/New Filter/840302/1405)

The WPF value calculated was 0.95. Inspection of the filter papers in the field after counting revealed a tear in the "outside" one. All "outside" counts were rejected.

Radon daughter concentrations and Working Levels were not directly required for the calculations of the WPF, as has been discussed. They were evaluated in order to describe the environmental conditions present during the field tests.

Radon daughter concentrations were determined by making the simplifying assumption that all the measured alpha activity is due to radon daughters. The calculations that generate concentrations and Working Levels using the modified Tsivoglou method were described by Thomas[13,14] for the specific case of 5 minute sampling time. In order to handle the reduction of data that originated from a range of sampling periods, a computer program was written for evaluating the elements of the transformation matrix T that converts concentrations* $\vec{C}$ into "normalized" count data $\vec{N}$ according to

$$T\,\vec{C} = \vec{N} \qquad \text{(Eq 2.1)}$$

where T and $\vec{N}$ are functions of the sampling time and depend on the counting time protocol. The general formulation of Yang Fu-Chia and Tang Chia-Yong[15] was employed when writing the computer program.

Once all times were fixed, equation 2.1 represents a system of linear equations. To solve it for the radon daughter concentration $\vec{C}$ the transformation matrix is inverted. The elements of the inverted matrices T^{-1} associated with the sampling times encountered in the study are listed in Appendix A.

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*RaA, RaB and RaC concentrations are the elements of the composition vector $\vec{C}$.

The filter collection efficiencies and self-absorption were taken as unity and zero, respectively, in the radon daughter calculations. They have no effect on WPF, because they cancel out*.

Unacceptable negative values of RaA, RaB or RaC concentrations resulting from the calculations appeared in 25% of the "outside" data and 43% of the "inside" measurements. Counting errors could account for many of these occurrences, but not all. A probable cause is the use of a constant concentration model to determine concentrations which were subject to temporal variations during the sampling periods[16]. Sampler pump fluctuations also contribute to the uncertainties in the measurements.

Working Levels were calculated directly from the normalized counts, potential alpha energies of the radon daughters and the elements of T^{-1} (previously described). Working Levels computed from data that contained negative concentrations were excluded from further analysis because their inaccuracy may have been greater than other WL data, but they were not deleted from the tables which present detailed results. Only one of the computed Working Levels is an unacceptable negative value; counting statistics are sufficient to account for the occurrence.

2.4.2 Measurements and Observations

Measurement results, workplace protection factors, and calculated radon daughter concentrations and Working Levels for the field testing of the AH-5* respirator are presented in Tables 2-2 to 2-25.

Workplace protection factors (labeled WPF_T) for each combination of test subject and type of respirator filter ("NEW" or "OLD") are given in the first twelve tables. In addition to WPF_T, the ratios of normalized counts in each of the count intervals are provided. All data that have been rejected (see previous section) are contained within parentheses, while readings missed in the field are identified with a dash.

The second set of tables, Tables 2-14 to 2-25, is arranged similarly to the first and presents radon daughter concentrations and working levels.

The workplace and work tasks of the test subjects varied considerably and were important aspects of the experimental design. A brief description of the test conditions for the AH-5* PAPR is provided in Table 2-26. These indicate that it was rare that a test subject remained in essentially the same area during any one sampling period.

Air velocities were measured at the chin exhaust port (V_E) and the temple areas (V_R - right side; V_L - left side). For the purposes of comparing the operation of the respirators V_E is the most significant parameter because most of the flow of air out of the respirator is through the chin exhaust port. Temple area measurements were made to identify leakage, but they may have little relationship to the volumetric rate of air escaping the respirator because the gaps between the user's face and the respirator were small or not easily identified. Air velocity measurements are given in Table 2-27.

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*The detector efficiencies for filter paper geometry were used in these calculations.

The air velocity measurements made at the beginning and end of shift were in agreement within experimental error*. Thus no major change in respirator performance was observed, but small differences would not be resolved by these measurements of limited precision.

2.5 Analysis

2.5.1 General

In this section the distribution of the test results is examined and appropriate mean values are reported. Analysis of variance (ANOVA), which assists in defining the range of applicability of the results, is presented. As a check on the method of extracting WPF from total counts, the ratios of the calculated Working Levels are also examined.

The statistical analysis made use of SPSS software that is amply documented[17, 18] Therefore, only brief comments on the methods are given here, generally as footnotes.

2.5.2 WPF Distributions and Mean Values

Inspection showed and ANOVA confirmed that "NEW" filters protected better than "OLD" ones, therefore the distribution of the "NEW" and "OLD" subsets of the WPF data were examined separately, using the Kolmogorov-Smirnov (K-S) test**. While for the "OLD" subset the K-S test indicated that both normal and lognormal distributions were adequate descriptions, the distribution of the "NEW" WPFs was clearly loguormal. Therefore, the appropriate parameters to describe the distribution of the test data are the geometric mean and geometric standard deviation. These are presented in Table 2-28, where K-S test results and the higher moments (skewness, kurtosis) are also given.

The lognormal nature of the distributions is in agreement with what is usually found for respirator protection factors, as well for FFs as for WPFs[19, 20].

Figure 3 presents the cumulative lognormal distribution of the WPFs determined for the AH-5* PAPR; the data points presenting the cumulative percentage of the tests (horizontal scale) in which a particular value of WPF was achieved. The straight lines represent the lognormal distribution computed from the test data.

The error bars shown at 50% indicate the 95% confidence interval for the geometric mean WPF for the entire population of people and equipment that the persons and respirators tested represent. The lines about half-way indicate the 95% confidence interval for the geometric mean WPF from the test itself, illustrating that mean values valid for the whole population are known with less precision than the mean values obtained for the test population***.

---

* Except that for subject F on 1984.03.01 the measurements indicated an increased flow at the end of the shift. The reasons for this result, which is contrary to expectations, are not known.

** The Kolmogorov-Smirnov nonparametric goodness-of-fit test compares the observed data and a theoretical cumulative distribution, no difference between these being the null hypothesis. The theoretical distributions tested in the present case were the ones defined by the mean values and standard deviations of the observed data.

*** The distinction in statistical terms is "fixed effects"/"random effects"; this is an ANOVA result.

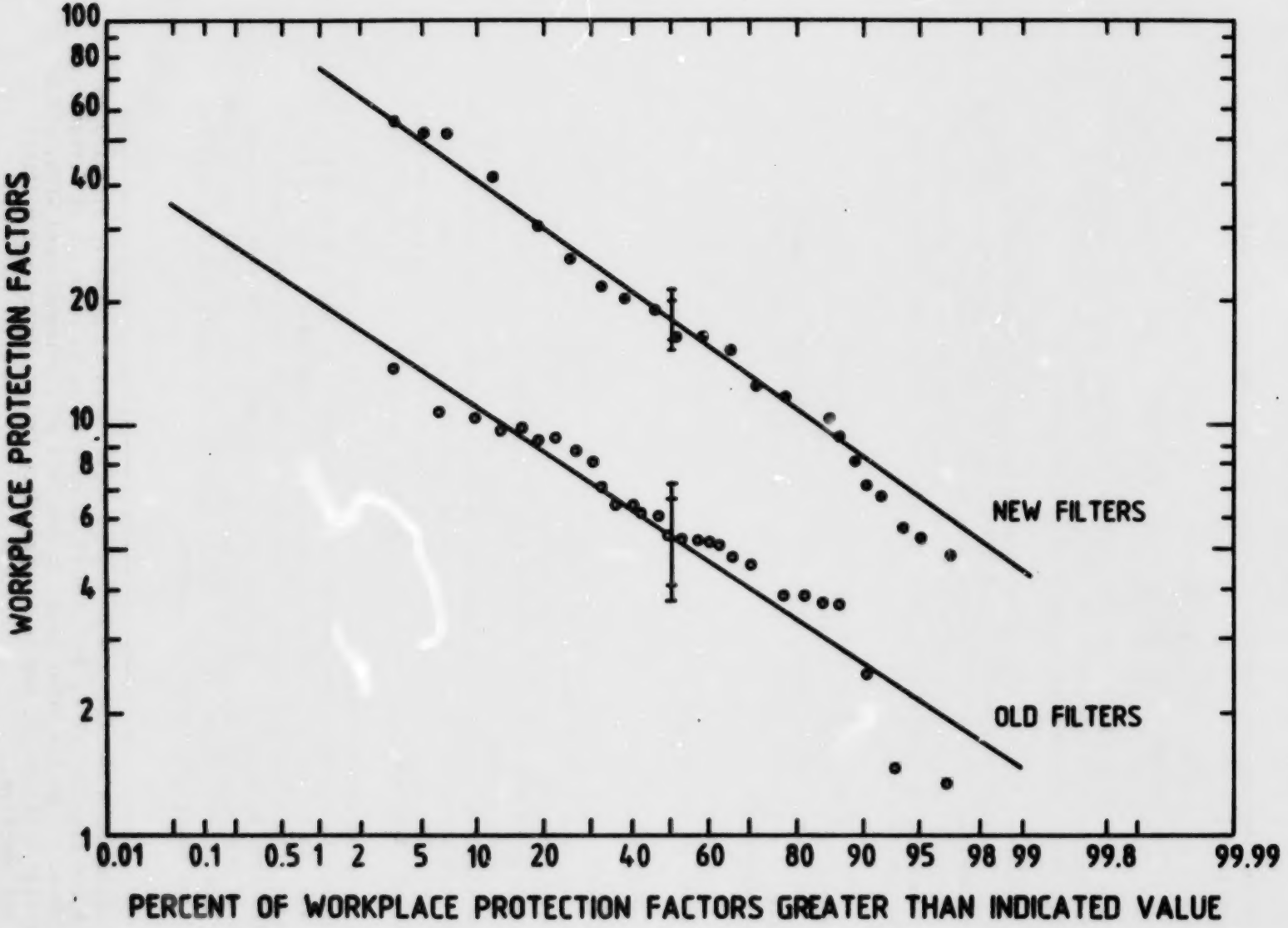

FIGURE 3: Workplace Protection Factor Distributions for the AH-5* PAPR

The mean values and the 95% confidence intervals for the means (valid for the entire population) are:

"OLD" filters WPF = 5.3 (3.9 - 7.3)

"NEW" filters WPF = 17.8 (13 - 24)

It was beyond the scope of the present work to determine the reasons for the difference between the performance of NEW and OLD filters. However, several likely contributing factors may be mentioned here:

A partial clogging of the filter gives rise to an increased pressure drop and to a reduction in flow. But our checks of the pressure drop across some OLD filters indicate $\Delta P < 20$ Pa, and the exit velocity measurements did not indicate any major difference in NEW/OLD flows. Clogging may also lower the efficiency because of channeling at a high velocity through the parts of the filter that remain open.

Electric charge contributes to the efficiency of filtration and there are several agents, which build up on the filter during use, that can cause loss of charge and diminished filtration[21, 22]. Oil from heavy equipment operation, humidity and small amounts of radioactivity are such agents present in the mine environment.

Even the repeated handling (i.e. daily removal/reinstallation) of the filters may contribute to diminished performance.

2.5.3 Analysis of Variance

As the previous section indicates, the workplace protection factors observed were scattered over a wide range. Measurement inaccuracies and the multitude of work-tasks and work situations contributed to this scatter. Analysis of variance (ANOVA) was done for the purpose of identifying user-dependent or equipment (i.e. respirator/battery/filter) dependent variations in respirator performance that might be superimposed on the event-related (i.e. test and task-related) random scatter. Furthermore, it was necessary to check that measurement results were indeed independent of the conditions (such as ambient WL and elapsed time) and parameters (such as sampling duration) of the tests.

It was not evident whether ANOVA of the WPFs or of the logarithms of the WPFs was more appropriate*, therefore ANOVA was run on both. An additional complication was due to the non-orthogonal experimental design**: there is no unique result from ANOVA, but several feasible procedures each yielding more or less different answers[18]. Fortunately, concordant answers were obtained regardless of the form of the dependent variable (WPF or log of WPF) and of the ANOVA approach (Experimental, Hierarchical, Regression), obviating the need for making choices among contradictory answers.

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* In principle, ANOVA requires the dependent variable to be normally distributed, which is not true for WPFs, but ANOVA is reputed to be tolerant of deviations from normality. On the other hand, an analysis of log-transformed WPFs, which are normally distributed, may be inappropriate if effects are not multiplicative but additive.

** i.e. unequal number of observations and missing observations in cells.

WPF data were examined with respect to the following independent variables:

(1) test subject;
(2) day, which identifies the tests on a given day with a given test subject;
(3) respirator filter "NEW" or "OLD";
(4) sampling period (T);
(5) PAPR air velocity (V_E);
(6) time elapsed since arrival underground Tc; and
(7) alpha activity pseudo-concentrations, obtained by dividing the sum of normalized counts by the sampling period (Cp).

Table 2-29 is a brief description of the ANOVA runs. It indicates what part of the data (OLD, NEW or All) was analyzed by which approach*. Some of the findings are also indicated, namely which effects were significant at the 0.01 or 0.05 level and which of the independent variables tested had no effect at 0.05 significance. The indications (WPF) and (log) mark the occurrences of differing answers from the analysis of WPFs and of their logarithms. The conclusions drawn from the analysis are the following:

1. When all data were analyzed, the nature of the filter, "NEW"/"OLD", explained the major part of the WPF variance.

2. The effect of the exit velocity V_E was significant, but regression coefficients obtained from the different ANOVA approaches were only in agreement within a factor of 4. The values in Table 2-30 indicate that a 10% (0.1 m/sec) drop in airflow appears to lower the WPF by 1-4 units.

3. In spite of the large differences between "NEW" and 4-day-"OLD" performance, no deterioration of performance with time elapsed during the shifts could be resolved: ANOVA indicated no effect of Tc on WPF.

4. The duration of the sampling period T had no effect on the results either; this tends to indicate the absence of systematic errors or artifacts related to this variable. Similar conclusions can be drawn, based on ANOVA of the NEW and OLD subsets**, regarding the absence of effects of Cp and hence of ambient WL.

5. The "OLD" WPF-results appeared independent of all of the variables tested***; none of them had a significant effect. Thus the scatter of the "OLD" WPFs appeared to be mostly random, unlike the "NEW" WPF results discussed below.

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* For the Hierarchical approach, the order of analysis selected is indicated in parenthesis.

** ANOVA of all data showed a significant effect of Cp, but this is probably an artifact (subject dependence in disguise), because the variables Cp and "subject" were not statistically independent.

*** V_E was not included because the simultaneous choice of V_E and "subject" was not feasible for the ANOVA of the "OLD" subset. Note also that "subject" and "days" coincide for this subset, they are essentially different labels for the same thing.

5. ANOVA of the "NEW" subset indicated subject dependence and "days"-dependence, which can be interpreted as the combined effect of subject, job, and of equipment condition (battery/filter/respirator condition). The proportion of variance explained by "days" was larger than the one explained by "subject"*, but no firm conclusions could be drawn regarding the reason for this difference.

In light of the dependence of the WPF on subjects or days it becomes an important consideration whether the study subjects or days were similar and belonging to the same population or did they differ significantly. The answer was provided by range tests** which indicated that the differences either between subjects' means or days' means were not significant at the 0.01 level. Thus study subjects and days can be regarded as a single homogenous population and the use of the mean WPF value (instead of several values specific to particular subjects, days or subsets) is justified. Furthermore, the homogeneity corroborates the assumption that the use of single WPF distributions is an adequate description that is valid for the whole user population.

The study was intended and designed to be representative of real-life conditions experienced at the workplace by any miner. Although this representativeness still remains an assumption, the analysis did not turn out any evidence that would contradict it. As far as we can see, the results should be valid for any miner who uses a properly functioning AH-5*, regardless of workplace, job or or breathing rate.

2.5.4 Working Level Ratios

One of the study objectives was to obtain a quantitative measure of the true protection (i.e. the true reduction in the dose to the user). In theory, the true protection could be given by the ratio of "outside"/"inside" Working Levels.

It was decided not to calculate WPFs on the basis of Working Levels for several reasons, some of which have been already discussed (i.e. the steady concentration model is not adequate; statistical errors in counting get amplified and result in unacceptable negative concentrations; all this renders a significant part of the data useless or questionable for WPF calculations).

An additional reason for not basing WPF on WL is the presence of thoron daughters and uranium dust in the mine atmosphere. In such a situation, a simple treatment of the counting data, which takes alpha counts emitted possibly by thoron daughters or uranium and converts them to radon daughter activity concentrations, is certainly inadequate.

Our choice of basing WPF on the ratio of total counts had the advantage of more precision and less loss of data. The method is also superior in its immunity to interference from thoron daughter or uranium activity, because for these long-lived activities count ratios are the proper WPFs.

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* It was not feasible to test simultaneously for the two variables because "days" was a subdivision of the "subject" classification.

** The Scheffe and the Modified LSD range tests were run in conjunction with Oneway ANOVA.

However, the question remained whether it is proper to replace Working Levels, which are a weighted sum of the counts in the three counting intervals, with a straight sum of these counts. The answer is "yes" if the protection is the same for all species, i.e. $WPF_{RaA} = WPF_{RaB} = WPF_{RaC}$. Although identical efficiencies for the removal of the three radon daughter species have been reported in the literature[21], a check of the results against calculated Working Levels appeared appropriate.

Figures 4 and 5 are scattergrams of WL against pseudo-concentrations (which are total "normalized" counts divided by sampling time). The proportionality indicated by the scattergrams confirms the identity (within errors) of WPFs and Working Level ratios* and confirms that protection did not depend on the nature of the radon daughter species.

3. RESPIRATOR USAGE

3.1 General

In the measurement of workplace protection factors, as many respirator use and respirator program effects as possible were eliminated by using the general criteria that 1) respirators be operated properly; and 2) that valid measurements be achieved through the proper use of the device. Workplace protection factors therefore represent the upper limits of the protection attained by respirator wearers because respirators may fail in use or may not always be used according to prescribed instructions. With a good respirator maintenance program the effects of equipment failure on the long term protection by the respirator can become negligible. Any deviation from the optimum WPFs will then be determined by the general use patterns associated with the respirator.

Powered air-purifying respirators offer a unique opportunity to describe patterns of use, particularly for the helmet type devices like the AH-5. With the dual role of providing head protection as well as respiratory protection the respirators are usually assigned to an individual and become an integral part of his/her safety equipment. They are used for a complete shift and generally on a regular basis. For the AH-5 PAPR proper use of the device (as described in the AH-5 operating manual[23], apart from the actual maintenance and initial size adjustments, is defined by wearing the respirator with the visor locked in the down position with the face seals pointing towards the face. The proportion of time the visor is worn in the correct position then becomes a practical index of proper usage. To assess the use characteristics of the AH-5 in underground uranium mining a formal survey was conducted among the majority of the users at the mine site.

The survey questionnaire had several objectives, namely:

1. to determine the fraction of the workshift the visor is worn in the correct "down" position;

2. to invite comments concerning the problems associated with the use of the respirators;

3. to identify the extent of respirator failure in use and the user's perception regarding the use and maintenance of the respirators; and

4. to identify factors related to respirator use patterns.

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* The geometric means of the WL ratios were 17.1 and 5.0, respectively, for "NEW" and "OLD"; well in agreement with the WPF results.

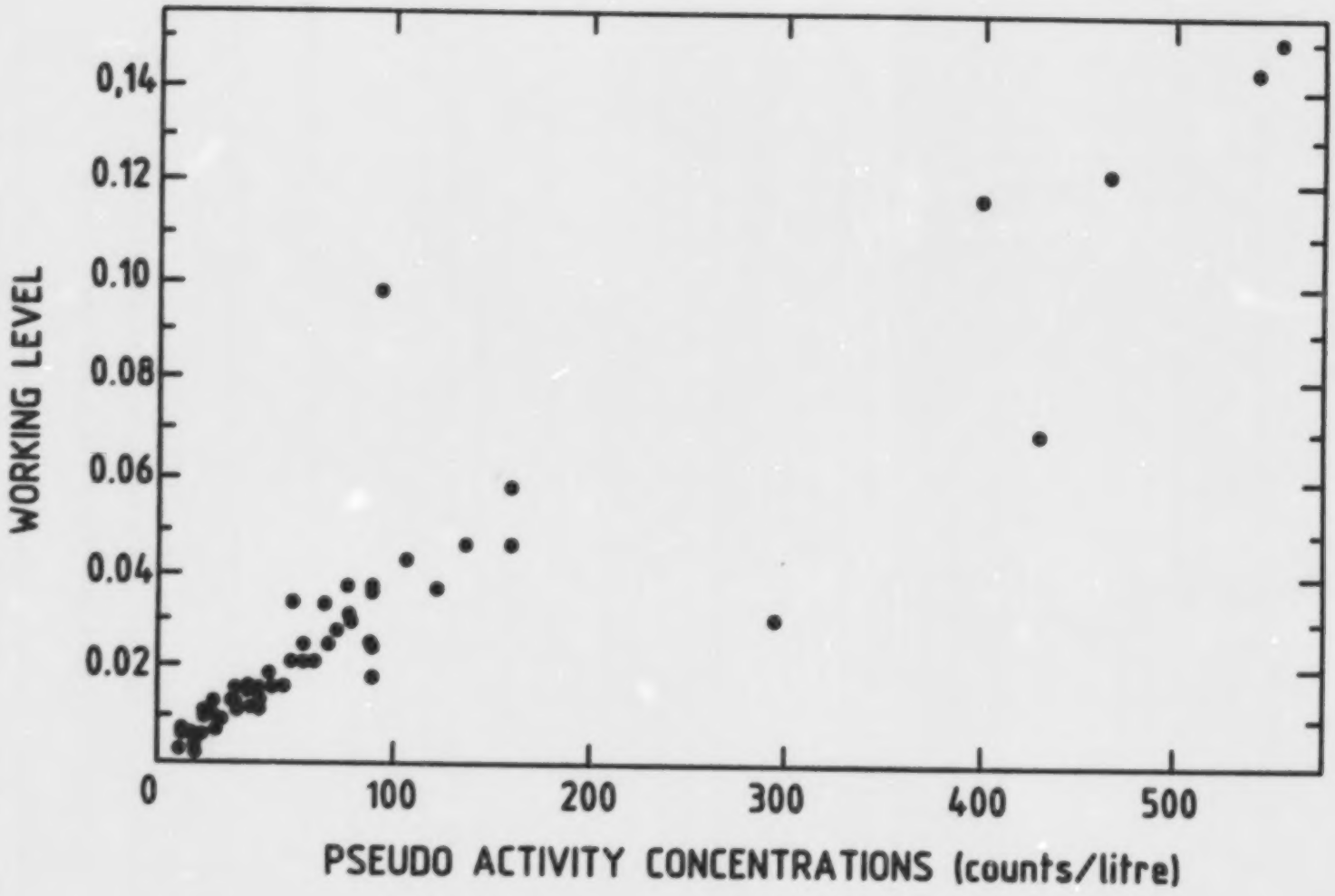

FIGURE 4: Scattergram of Pseudo Activity Concentrations (Cp) and Working Levels (WL) (Inside)

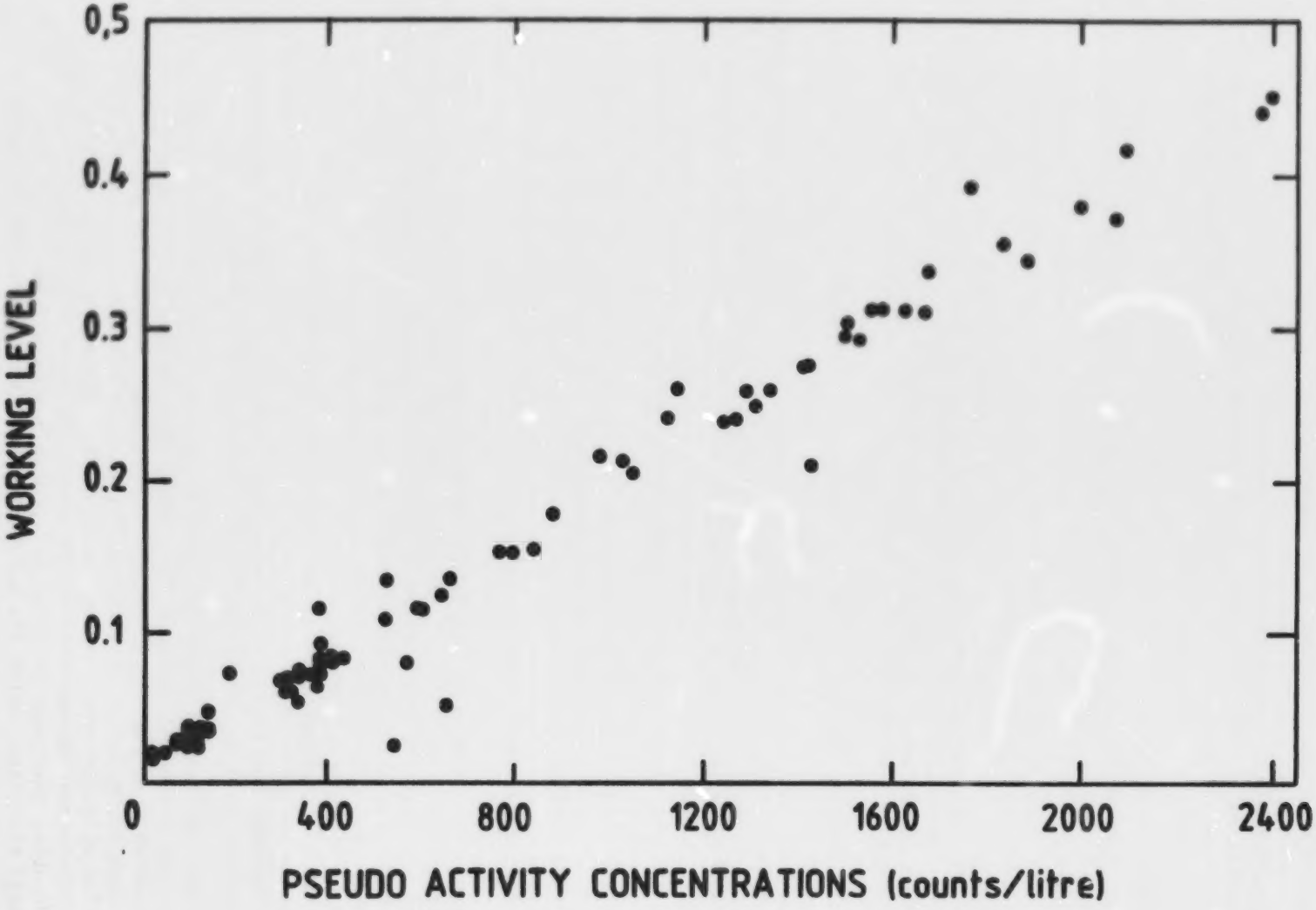

FIGURE 5: Scattergram of Pseudo Activity Concentrations (Cp) and Working Levels (WL) (Outside)

So that information could be obtained on the realtive importance of some factors affecting usage, several questions requiring scaled subjective responses to commonly reported use problemr were included in the questionnaire. Scaling was based on qualitative observations of PAPR users underground and informal discussions with AH-5 users at another mine site.

Survey questionnaires (Appendix B) were distributed shortly before normal cage time to approximately 250 miners over a two day period. Completed questionnaires were collected at the end of the shift; a total of 207 were returned.

3.2 Results

The general background of the respondents obtained from the replies to the first three questions indicated that essentially all of those surveyed were regular users. Eighty percent had used the PAPR for more than one year and slightly more than 15 percent had used it for four or more years. Based on this experience (Table 3-1) respirator use patterns and attitudes should be well established, and unless significant changes were to occur in the respirator program, the use of the respirators is unlikely to change. The job classifications associated with the regular PAPR users are given in Table 3-2. At the study site, mandatory wearing of respirators is not usually required, thus all respondents were voluntary users.

Though failures are reported to be infrequent, 65.5 percent of the PAPR users noticed a reduction in the light intensity of their cap lamp or diminished respirator airflow (Table 3-8) during the shift. Since both the respirator and cap lamp operate from the same battery reduced light intensity implies a reduced airflow to the respirator and consequently reduced protection. Because a significant number of respondents had a perception of reduced airflow (which may be difficult to detect unless differences are large) either 'most of the time' or 'always', the performance of the respirator may not always be at the desirable level.

Reduced airflow may arise for several reasons. Insufficient battery charge may be the most obvious but reduced fan/motor efficiency can also contribute. Reduced operating efficiencies can occur if the blower assembly is dirty or if the filter pressure drop increases. The extent of reduction in airflow, irrespective of the actual cause, should be investigated.

Some general use patterns of the AH-5* are described in Tables 3-9 and 3-10. These data indicate that in most circumstances the visor is lifted while communicating and that the visor is worn in the down position by approximately one half of the respirator users when travelling to and from the cage or lunchroom. It is likely that these observations are not independent. Because noise levels generated by the respirator are relatively low, the principal reasons for the 'visor lifting' requirement in communicating are that hearing protectors are used extensively underground and some muffling of the voice is created with the visor in the down position. It is necessary to raise the visor to be understood. These problems could be compounded in high-noise environments.

The responses to the most important question of the survey on the duration of proper use are presented in Table 3-11. Though a large fraction of those surveyed indicated that the visor was worn properly for most of the shift, when one considers the majority of workers, for example 90%, then proper usage is achieved for slightly more than one half shift. Since the number of people surveyed represents the majority of the users and experience among the users is considerable, the usage patterns are probably well settled. The distribution of the usage responses, which are subjective estimates, is shown in Figure 6.

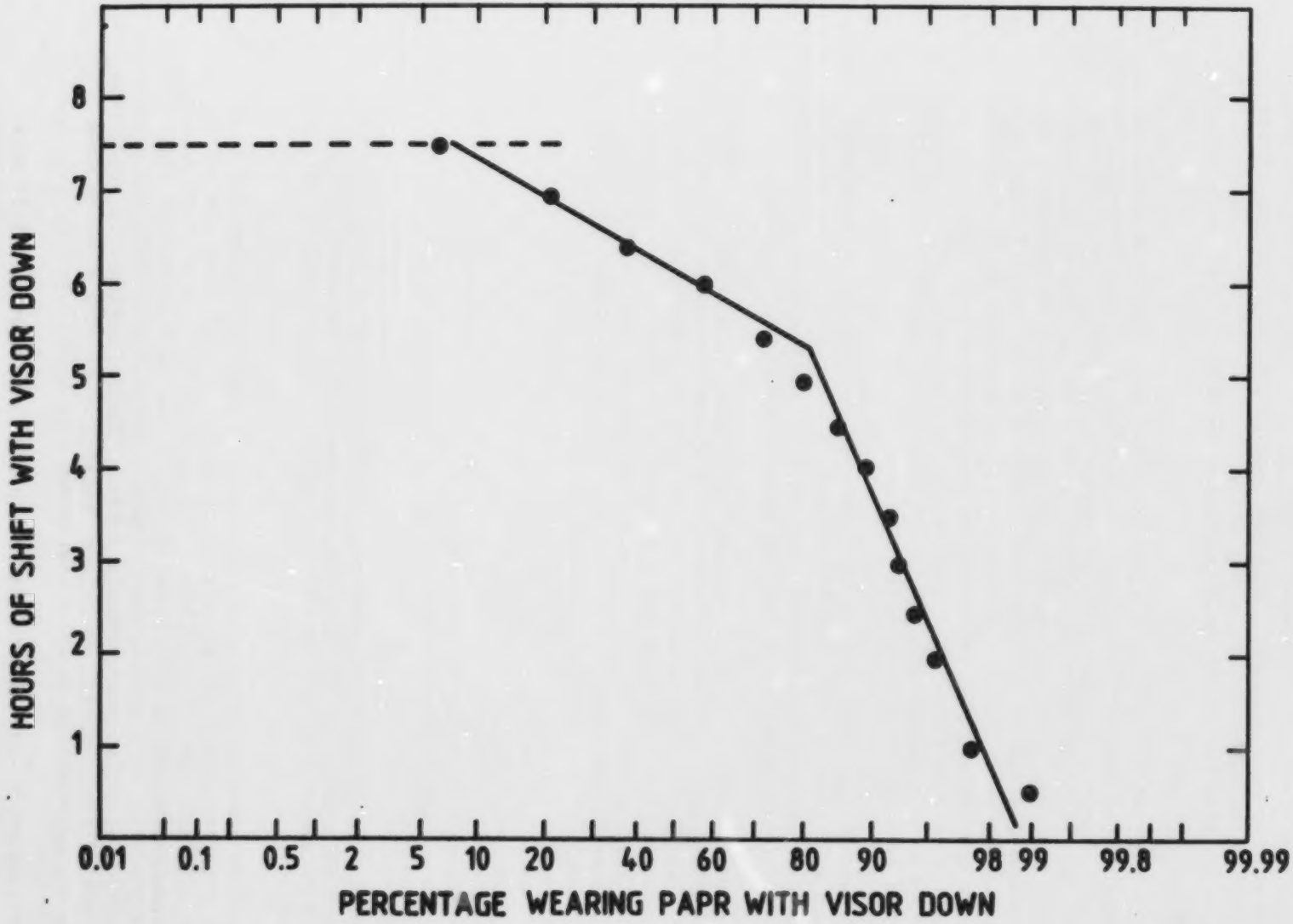

FIGURE 6: Distribution of AH-5* Usage During Shift

To most users the AH-5* was considered acceptable and problems associated with use have in general been accepted. This was certainly evident in some of the reponses to the last survey question requesting general comments. The fact that those expressing dissatisfaction with the device remain voluntary users attests to this fact.

The comments provided in reply to the last question were largely a repeat of those already reported yet provide an effective means of summarizing the results of the survey. Table 3-12 lists the main comments observed, their frequency, and possible action which could be taken to improve the situation. Implementing the suggested improvements may change the use patterns somewhat, however, the impact of possible improvements is unknown. Regardless of whether respirators are positive pressure or negative pressure devices, their use will cause some discomfort to the wearer. The extent of the discomfort and the impact on use will depend not only on the obvious factors such as respirator design and the work tasks and work environments, but on the individual user himself and his attitudes and perceptions towards respirator use.

Many job classification descriptions were received from the respondents and those listed in the table were categorized using a keyword approach. Because such information was not specifically required in the examination of the survey results no additional grouping of the job categories was performed.

Table 3-3 summarizes the responses obtained regarding the comfort associated with the respirator. Approximately 80% find that the respirator is comfortable 'most of the time' which may be related to the voluntary use of the PAPR. Comments were received from 91 of the 207 surveyed concerning some comfort aspect of respirator use. Quite often multiple responses were provided, however, not all dealt specifically with comfort. The major comments (ranked) indicated were:

-the respirator falls off when bending over,
-the power cord gets tangled up,
-the unit is heavy,
-the unit is bulky and awkward,
-the headband is irritating,
-too hot/cold.

Eighteen of the respondents indicated reduced visibility as a contribution to discomfort. When specifically asked how they would rate the visibility when using the PAPR almost all users stated that visibility was usually good (Table 3-4).

The majority of comments provided in the remaining part of the question identified two significant visibility related problems, namely: that the visor fogs up (41/70) and the visor easily becomes scratched (16/70). Several responses included comments regarding restricted visibility due to the physical design of the PAPR (up vision, side vision, down vision). These were a small but significant fraction of the written comments (~10%). Though fogging will arise from a combination of environmental conditions (humidity) and work rate, reduced visibility due to scratched or dirty visors can easily be corrected.

Work activities which cause distress to the worker when wearing a PAPR were briefly described by about 70% of those surveyed. Most of the responses referred to strenuous work activity, work in confined spaces, or work which required bending over. These responses parallel the comments provided in questions 4 and 5 as fogging is most likely to occur at high work rates and the bulkiness of the respirator could affect work in confined areas. Summaries of these responses are given in Table 3-5.

Questions 8 and 9 were included to obtain indications of the user's experience with the respirators. In-use failures were encountered by a little more than half of those surveyed (56%). Considering the length of experience using the devices, failures appear to be infrequent and this is supported by the fact that only 6% of the respondents indicated that failures occurred 'often'. Most of the failures reported were related to the motor/fan assembly or the battery (relative frequency of responses 48% and 32% respectively). Few mechanical problems were described. Most users found that repairs were satisfactory. Tables 3-6 and 3-7 provide summaries of the respirator failure experience.

It is a generally accepted observation that usage is most affected by training [24]. Considering the similarity between the present AH-5* and potential improved models, the item most likely to result in the greatest dose reduction is the encouragement of longer proper use periods among the workers.

4. MODEL AH-3 WORKPLACE PROTECTION FACTORS

4.1 General

The technology associated with PAPRs has undergone several new developments in recent years, the most significant being the availability of high efficiency respirators. These respirators, with an increase in filter efficiency by an order of magnitude over the AH-5 and AH-5* PAPRs currently being used in the Canadian mining industry, have a potential for a greater degree of respiratory protection. To investigate the potential of the newer type PAPRs a high efficiency Airstream helmet was used for several WPF measurements (Airstream AH-3); see Figure 7.

The AH-3 PAPR is similar to the AH-5, utilizing essentially the same headgear and faceshield assemblies. The principal differences exist in the design and location of the filter/blower and battery assemblies. Respirable air in the AH-3 is delivered to the helmet through a breathing tube connected to the "air supply" worn on the user's belt. In addition, a perforated Tyvec seal with an elasticized edge is used for the respirator/man seal instead of the soft plastic flap-type seal used in the AH-5.

Subject A, the leaching attendant involved in the AH-5* WPF measurements, was the only participant in the AH-3 study. His selection was made primarily on the basis of availability and the fact that he had been using the AH-3 on an experimental basis for several weeks prior to the AH-5* study. He was familiar with the procedures and requirements for WPF measurements having already participated in the AH-5* measurements.

The respirator used for the measurements was the same one Subject A had been using on a trial basis. It was examined by study personnel before testing and components showing any defect were replaced. No airflow checks were made directly on the respirator. Therefore, there is no record of the actual output produced by the battery/blower unit.

4.2 Measurements and Observations

Measurements were made during two shifts using equipment and data handling procedures that were identical to those used in the AH-5* measurements.

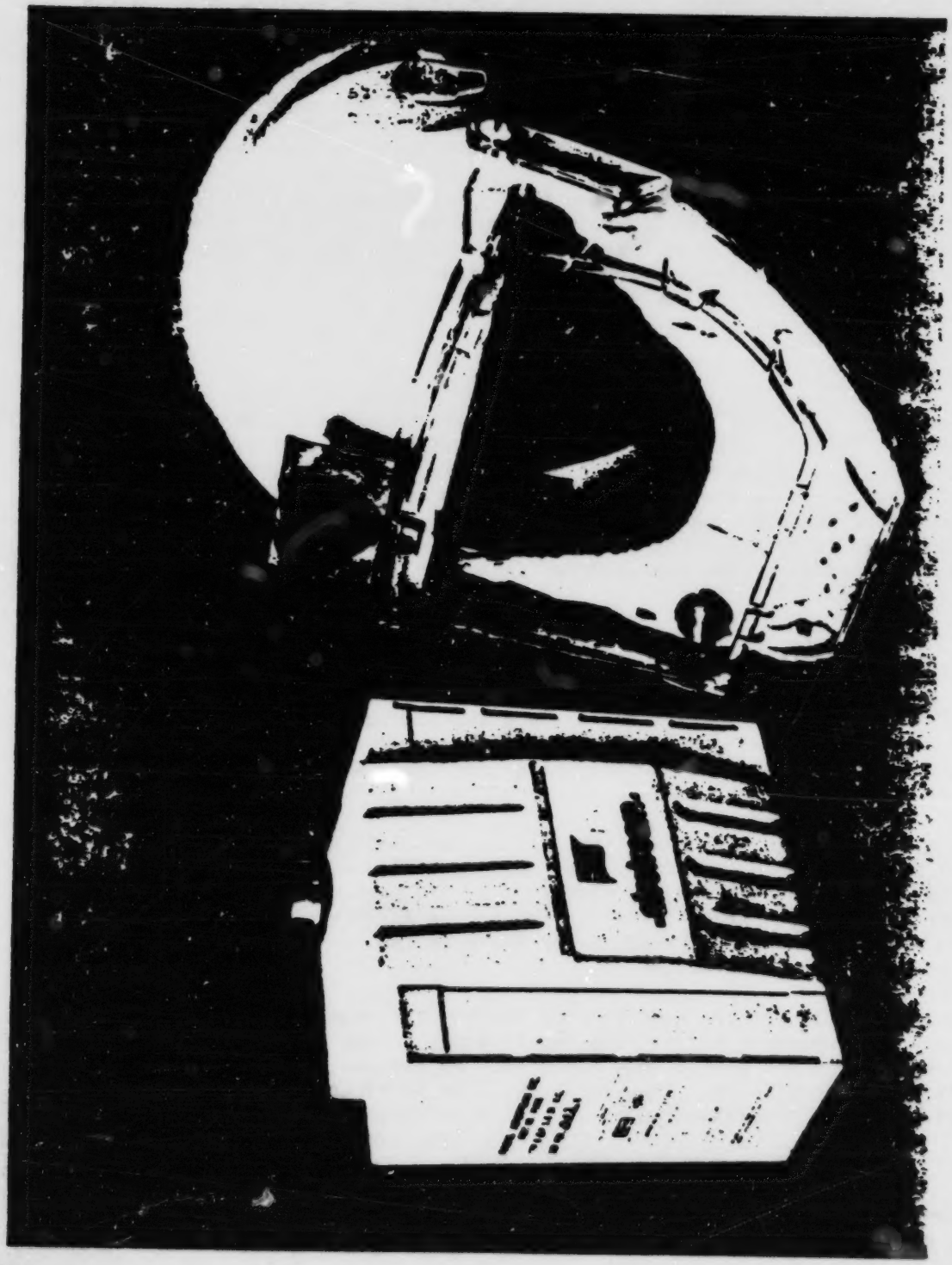

FIGURE 7: Racal Airstream AH-3 Helmet

Air velocity measurements around the periphery of the AH-3 were made at the beginning and the end of each shift. Though the respirator sealing arrangement was different from the AH-5* because of the perforated fabric, measurement locations already established (Figure 2) were used. A direct comparison of V_E between the AH-5* and AH-3 respirators is not practical because of the difference in face seal methods. Differences in V_E were observed for the AH-3 at the two measurement times, with V_E larger at the end of the shift one day and approximately the same on the other measurement day. Using V_E as a gross indicator of performance, the operation of the AH-3 did not appear to be significantly different on the two days. Temple area velocities were definitely higher than those observed with the AH-5*; this may be a consequence of the greater exhaust pressure drop created by exhausting the air in the AH-3 through many tiny holes rather than a single large opening. The air velocity measurements are presented in Table 4-1.

Efficiency measurements and workplace protection factors are given in Table 4-2 and the corresponding radon daughter concentrations and working levels are presented in Table 4-3. Not all of the WPF measurements meet the criterion for valid samples*.

The work and activities of Subject A did not differ during sampling periods except that on 1984.03.09 considerably more travel through the leaching areas was encountered.

Excluding the invalid measurements, five WPF measurements remain from the two days of sampling (10, 189, 149, 297, 114). The four high values have a geometric mean of 176 and a geometric standard deviation of 1.5; it is not clear whether the WPF value of 10 found belongs to the distribution. The protection achieved with the AH-3 was greater than that achieved with the AH-5* for Subject A and this would likely be the case for other individuals as well. However, the distribution of AH-3 data for larger populations may not be well represented by a single individual's workplace protection factors. Evidence of this fact has been described in other WPF measurements in other industries. As a result the measurements and observations obtained with the AH-3 should be regarded as preliminary, being more suited to establishing a protocol for more extensive study rather than establishing the degree of protection provided by the respirator.

Regarding the protocol used to establish a set of representative WPF measurements different requirements may be necessary. First, if the assumption is made that WPFs will extend beyond the upper range (~300) experienced in Subject A WPF data, then preselection of the work environment would be required to ensure adequate sensitivity for interior sampling of the respirator, otherwise an upper boundary will exist in the set of WPF data. It is doubtful whether WPFs of even 300 could be measured in most active production areas of the mine because of low WL environments.

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* During the 1984.03.08/920 sample period the AH-3 blower ceased functioning (momentarily) due to a poor battery connection at the AH-3 battery pack and a similar situation occurred during the 1233 sample on 1984.03.09. In fact the connection failed on two other occasions but these did not occur during sampling. A complete loss of flow is easily detected by the wearer and since no others were observed, proper connections were assumed for the remaining sampling periods. One other WPF sample was ruled invalid because the subject had to lift the visor during the sampling period (1 minute 1984.03.09/923).

Qualitative assessments of the AH-3 made by the study personnel during the period the respirator was used for workplace protection factor measurements indicate that there were some use/performance characteristics different from the AH-5* (AH-5). Any program that involves the AH-3 use underground should address the problems indicated by the preliminary observations that follow.

In addition to the problems experienced with the battery supply cord other problems were noted with the extended (complete shift) use of the device. The AH-3 was far more susceptible to fogging of the visor than the AH-5*. This was probably caused by the Tyvec seal arrangement which slowed the clearing of exhaled breath from the respirator (or trapping exhaled breath in the respirator). The high humidity in the leaching areas may also have played a role in any tendency towards fogging. The Tyvec seal and the additional weight of the blower unit caused an increase in discomfort as the shift progressed. The blower unit and the breathing tube are susceptible to damage in the underground work environment.

Breathing tube damage could occur when wearing the respirator on heavy equipment (personnel carriers, scoop trams, etc.) where banging against backrests may dislodge the clip on filters on the blower unit or damage the plastic housing of the "airpack".

The AH-3 and AH-5 have more design similarities than differences but usage and operating experience could differ. The AH-3 is a more complex respirator and may require a higher level of training among its users and require frequent program reviews to maximize any increase in protection provided by the device.

5. EFFECTIVE AND ASSIGNED PROTECTION FACTORS

The overall effectiveness of a respirator is determined by the WPF and by the proportion of time during the shift (f) that it is worn properly. The total daily dose to the user working in an ambient activity concentration Co is then proportional to an effective concentration C_{eff}, given by

$$C_{eff} = (1 - f)\,Co + fCo/WPF \qquad \text{Eqn 5-1}$$

where the first term represents non-use and the second proper use. An effective protection factor (EPF) may be defined as the ratio Co/C_{eff}, this leads to

$$EPF = 1/(1 - f + f/WPF) \qquad \text{Eqn 5-2*}$$

It can be seen by inspecting Eqn 5-2 that non-use (f = 0) results in EPF = 1 and that EPF approaches the WPF as f tends to 1.

On the basis of the user survey, which yielded the median value of f = 0.83 (i.e. 6.25 hours proper use in 7.5) and of the WPF study, from which one may extract a nominal combined value $\overline{WPF} \cong 10$ to represent week-long use (i.e. "NEW" + "OLD" combined), the median EPF may be estimated as $\overline{EPF} \cong 4.0$ for the AH-5*.

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*The simple model of constant concentration (working level), which is implied here, allows a generalized analysis of the impact of usage.

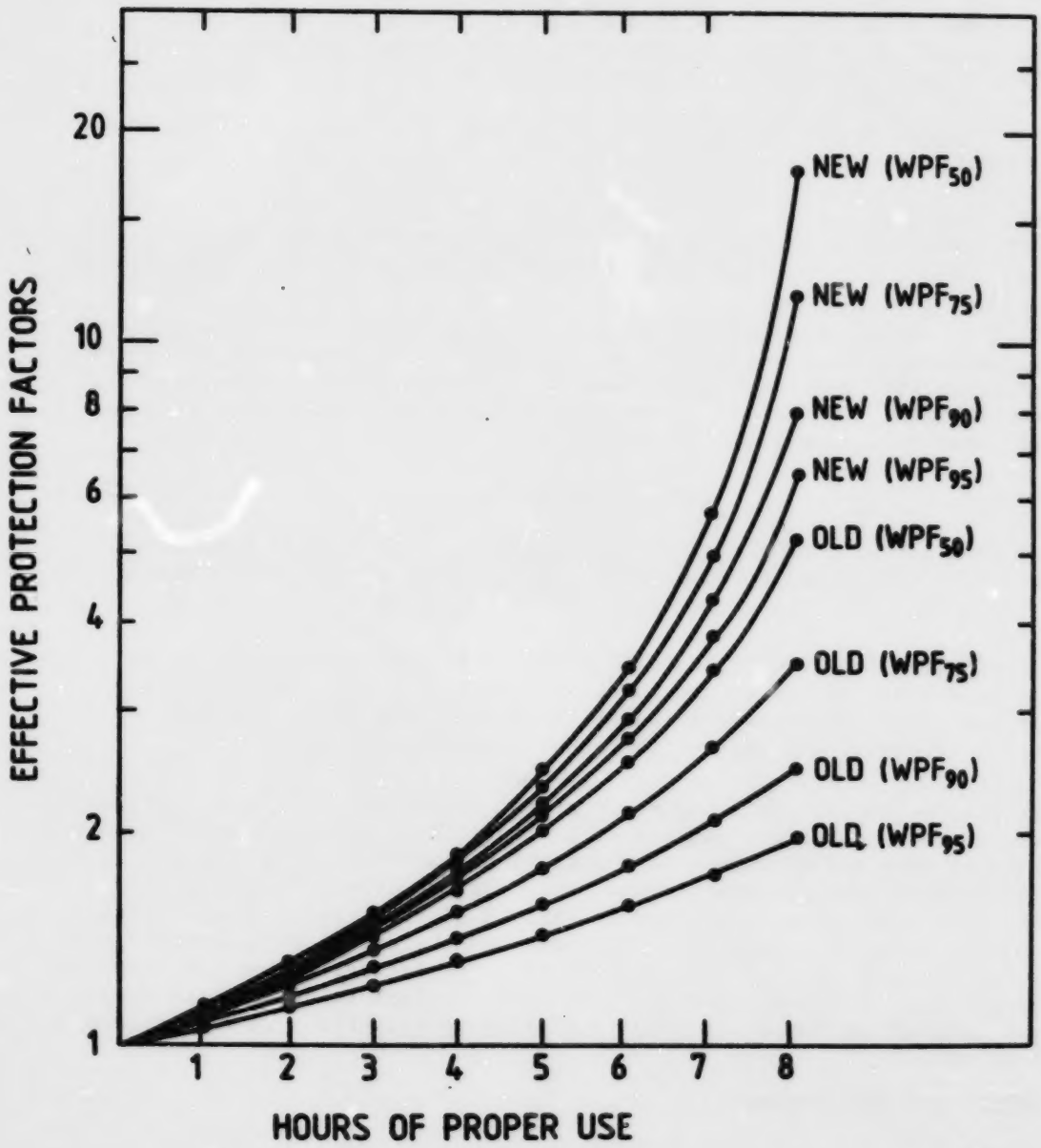

FIGURE 8: Effective Protection Factors for the AH-5* In Underground Uranium Mining Environments

A consideration of the usage pattern, which is reflected in the EPF, is very important when assessing respirator performance. The following conclusions can be drawn regarding the "typical" 6-hour-per-shift user:

1. The average daily radon daughter exposure of the user is reduced by a factor of about four (i.e. $\overline{EPF} \approx 3.6$).

2. Replacing the AH-5* with a higher efficiency respirator would result only in a marginal improvement. For example the use of the AH-3 would increase the EPF from 3.6 to 4.9.

3. Improving the usage pattern is the most efficient way of improving protection.

4. The question of filter reuse should not be considered without reference to the usage pattern. The effective protection of the 6-hour user is: EPF = 4.1 with "NEW" filters and EPF = 2.8 with "OLD" filters.

It should be noted, however, that decisions on respiratory protection are rarely based on average values, but rather on Assigned Protection Factor (APF), which express the protection guaranteed to a specified high percentage of the respirator users. APF values may be read directly from the graphs in Figure 3. or calculated according to

$$APF = \overline{WPF} / \sigma^{Z} \qquad \text{Eqn 5-3}$$

where Z is a property of the normal distribution. Values of Z = 0, 0.675, 1.28 and 1.64 correspond to cumulative probabilities of 50, 75, 90 and 95 percent. (Note that σ is the geometric standard deviation.)

Effective Protection Factors, calculated for different APFs are shown as functions of hours of proper use in Figure 8. Once the tolerance level (percentage) on which the APF is based is decided, and the proportion of proper use is known, the protection can be read from the graph.

The use of powered air purifying respirators for protection against inhalation exposure to radon daughters can result in significant reduction in WL exposures to miners in most underground mining situations when the units have a high acceptance level among miners and are operating properly. Extending the results to develop program protection factors however requires quantitative knowledge of respirator failure occurrences and the extent of diminished respirator air flow due to battery power drain. The latter, though not directly observed in the study was reported to be common. Failure occurrences do not appear to significantly affect long term exposure reductions in the program at the study site.

6. SUMMARY AND CONCLUSIONS

6.1 General

The results and conclusions obtained in this study are based on evaluations of one type of powered air-purifying respirator which is a slightly modified version of the standard Racal Airstream AH-5. Because the modifications were slight and the protocol for the field evaluations largely eliminated any effects due to the differences between the modified and unmodified versions, the workplace protection factors should be representative for both models.

The quantitative results of the miners' survey however may not be applicable outside the immediate program from which they were derived, because of the influence worker training, respirator maintenance and management policy have on respirator use and on employee perceptions of hazards and respirator use.

6.2 Efficiencies

Measured Workplace Protection Factors for the PAPR with "NEW" filters installed in the device at the beginning of the shift were lognormally distributed with a geometric mean of 17.8 and a geometric standard deviation of 1.84 (n = 59).

Measured Workplace Protection Factors for the PAPR with "OLD" filters (4 shift prior use) installed in the device were lognormally distributed with a geometric mean of 5.3 and a geometric standard deviation of 1.79 (n = 30).

The cause of the difference in the performance of the PAPRs equipped with "NEW" filters or the "OLD" filters was not identified. (Theory leads to the following conjectures: filter loading reduces the air flow; moisture, diesel fumes and radon daughters reduce filter efficiency; filter damage related to reuse and maintenance; unidentified causes.)

Efficiencies of the helmet-type powered air-purifying respirators in conditions of actual use are considerably lower than what is expected on the basis of filter efficiency alone.

Air velocity measurements at the chin exhaust port of the respirators did not indicate any drop in respirator airflow in the course of a shift. Neither did ANOVA indicate any significant effect of the elapsed time of use in the course of a shift on the measured efficiencies.

A preliminary study of the Airstream AH-3 model, as used by a single test subject, yielded WPF = 176, which was the geometric mean of four measurements. However, the result of one measurement, not included in the mean, was WPF = 10.

6.3 Respirator Usage

The Airstream AH-5* had a high degree of acceptance among the 207 miners responding to the survey, with more than 80% of them indicating that good visibility and comfort were achieved most of the time.

Most use problems occurred during strenuous work activities or when bending over.

Most miners lift the visor when communicating.

About one half of the surveyed miners travel to and from the workplace with the visor up.

Respirator failures were infrequent for the majority of users. Those occurring were usually related to either the motor/fan assembly or battery.

Reduced performance of the Airstream AH-5* assembly (cap-lamp/respirator) was reported to occur with a high frequency with 65.5% of those surveyed indicating noticable changes.

Respirator usage among the surveyed miners indicated that 72.5% of the workers use the Airstream AH-5* with the visor down for 6 hours or more of the workshift.

6.4 Protection Factors

Long term protection of the worker is affected primarily by the level of use of the respirator.

The prevailing usage pattern should be considered whenever respirator performance or filter reuse are evaluated.

For the "typical" 6 hour per shift user the effective protection factors are: EPF = 4.1 with "NEW" filters and EPF = 2.8 with "OLD" ones.

The Assigned Protection Factors, assigned at the 90% tolerance level and at 50% confidence, are APF_{90} = 8.2 with "NEW" filters and APF_{90} = 2.5 with "OLD" ones. Using these values to calculate the effective protection guaranteed to 90% of the 6 hour users one obtains EPF_{90} (6 h) = 3.4 with "NEW" filters and EPF_{90} (6 h) = 2.0 with "OLD" ones.

To have a protection of 2, which is equal to the dose credit presently applied, guaranteed to 90% of the users at 50% confidence requires that users wear the respirator with the visor down for 4.3 hours or more per shift with "NEW" filters and for 6 hours or more per shift with "OLD" ones.

Table 2-1: Job Classifications Of Test Subjects

SUBJECT	CLASSIFICATION
A	Leaching Attendant
B	Electrician
C	Conveyor Operator
D	Driller (Heavy Equipment)
E	Pipefitter
F	Scoop Tram Operator
G	Scoop Tram Operator

TABLE 2-2

SUMMARY OF AHS TEST RESULTS FOR SUBJECT A

DATE	CAGE TIME	SAMPLE TIME	SAMPLE PERIOD	FILTER	Normalized Inside Counts			Normalized Outside Counts			Workplace Protection Factors			
					$\frac{N_{2-5}}{cQ}$	$\frac{N_{6-20}}{cQ}$	$\frac{N_{21-30}}{cQ}$	$\frac{N_{2-5}}{cQ}$	$\frac{N_{6-20}}{cQ}$	$\frac{N_{21-30}}{cQ}$	WPF_{2-5}	WPF_{6-20}	WPF_{21-30}	WPF_T
840228	640	823	30.	N	346.	1507.	772.	7407.	31031.	16905.	21.4	20.6	21.9	21.1
840228	640	935	33.	N	630.	2721.	1480.	9430.	39250.	22050.	15.0	14.4	14.9	14.6
840228	640	1138	37.	N	2853.	6152.	(739.)	9290.	38255.	21540.	3.3	6.2	-	5.3
840228	640	1225	30.	N	88.	359.	196.	2722.	11595.	6365.	31.0	32.3	33.4	32.5
840228	640	1300	30.	N	415.	1802.	(2112.)	8656.	35290.	19680.	20.9	19.6	-	19.8
840227	640	900	32.	N	211.	932.	578.	1930.	11660.	4864.	9.1	12.5	8.4	10.7
840227	640	950	33.	N	164.	722.	380.	1994.	8564.	4789.	12.2	11.9	12.6	12.1
840227	640	1058	30.	N	99.	367.	186.	1251.	5741.	3271.	12.7	15.6	17.5	15.7
840227	640	1255	27.	N	128.	555.	303.	1918.	8485.	4962.	15.0	15.3	16.5	15.6

( ) Invalid data

TABLE 2-3

SUMMARY OF AHS TEST RESULTS FOR SUBJECT A

DATE	CAGE TIME	SAMPLE TIME	SAMPLE PERIOD	FILTER	Normalized Inside Counts $\frac{N_{2-5}}{\epsilon Q}$	$\frac{N_{6-20}}{\epsilon Q}$	$\frac{N_{21-30}}{\epsilon Q}$	Normalized Outside Counts $\frac{N_{2-5}}{\epsilon Q}$	$\frac{N_{6-20}}{\epsilon Q}$	$\frac{N_{21-30}}{\epsilon Q}$	Workplace Protection Factors WPF_{2-5}	WPF_{6-20}	WPF_{21-30}	WPF_T
840229	640	658	39.	0	292.	1322.	1031.	389.	1754.	1193.	1.3	1.3	1.2	1.3
840229	640	842	30.	0	1876.	7640.	4182.	-	27753.	15661.	-	3.6	3.7	3.7
840229	640	921	30.	0	1846.	7747.	4391.	6740.	28080.	15657.	3.7	3.6	3.6	3.6
840229	640	1000	30.	0	1324.	6557.	3664.	7224.	29487.	16695.	4.7	4.5	4.6	4.5
840229	640	1040	30.	0	1372.	5645.	3270.	5739.	23857.	13333.	4.2	4.2	4.1	4.2

( ) Invalid data

TABLE 2-4

SUMMARY OF AH5 TEST RESULTS FOR SUBJECT B

DATE	CAGE TIME	SAMPLE TIME	SAMPLE PERIOD	FILTER	Normalized Inside Counts $\frac{N_{2-5}}{\epsilon Q}$	$\frac{N_{6-20}}{\epsilon Q}$	$\frac{N_{21-30}}{\epsilon Q}$	Normalized Outside Counts $\frac{N_{2-5}}{\epsilon Q}$	$\frac{N_{6-20}}{\epsilon Q}$	$\frac{N_{21-30}}{\epsilon Q}$	Workplace Protection Factors WPF_{2-5}	WPF_{6-20}	WPF_{21-30}	WPF_T
840227	710	850	39.	N	-	87.	50.	-	1964.	1134.	-	22.7	22.9	22.8
840227	710	929	31.	N	19.	-	19.	341.	1319.	780.	17.8	-	40.9	29.4
840227	710	1007	28.	N	(1.)	17.	14.	207.	1243.	744.	-	75.1	53.2	64.1
840227	710	1140	27.	N	4.	31.	11.	286.	1305.	786.	74.9	42.8	68.6	51.9
840227	710	1215	25.	N	-	67.	22.	-	1110.	627.	-	16.5	29.0	19.5
840227	710	1247	25.	N	18.	60.	19.	221.	1117.	658.	12.4	18.7	34.5	20.6
840228	710	815	30.	N	74.	254.	163.	1069.	4204.	2448.	14.4	16.6	15.0	15.7
840228	710	855	30.	N	19.	102.	47.	1114.	4536.	2436.	58.0	44.6	51.3	48.0
840228	710	932	33.	N	28.	96.	50.	427.	1904.	1054.	15.5	19.8	20.9	19.5
840228	710	1015	30.	N	23.	66.	38.	1076.	4556.	2545.	46.3	68.6	67.6	64.3
840228	710	1042	30.	N	63.	266.	137.	1318.	4839.	2742.	21.1	18.2	20.1	19.1

( ) Invalid data

TABLE 2-5

SUMMARY OF AHS TEST RESULTS FOR SUBJECT B

DATE	CAGE TIME	SAMPLE TIME	SAMPLE PERIOD	FILTER	Normalized Inside Counts			Normalized Outside Counts			Workplace Protection Factors			
					$\frac{N_{2-5}}{\epsilon Q}$	$\frac{N_{6-20}}{\epsilon Q}$	$\frac{N_{21-30}}{\epsilon Q}$	$\frac{N_{2-5}}{\epsilon Q}$	$\frac{N_{6-20}}{\epsilon Q}$	$\frac{N_{21-30}}{\epsilon Q}$	WPF_{2-5}	WPF_{6-20}	WPF_{21-30}	WPF_T
840229	710	800	45.	0	445.	1833.	1225.	2372.	9864.	5522.	5.3	5.4	4.5	5.1
840229	710	850	30.	0	236.	(3298.)	530.	1293.	5498.	3116.	5.5	-	5.8	5.7
840229	710	930	30.	0	289.	(3147.)	599.	1396.	5837.	3237.	4.8	-	5.4	5.2
840229	710	1010	30.	0	233.	(3172.)	593.	1439.	5764.	3438.	6.2	-	5.8	5.9
840229	710	1205	30.	0	324.	(3952.)	813.	1403.	5903.	3227.	4.3	-	4.0	4.1
840229	710	1305	60.	0	529.	1647.	1098.	2320.	9689.	3960.	4.8	5.9	3.6	4.9

( ) Invalid data

TABLE 2-6

SUMMARY OF AMS TEST RESULTS FOR SUBJECT C

DATE	CAGE TIME	SAMPLE TIME	SAMPLE PERIOD	FILTER	Normalized Inside Counts			Normalized Outside Counts			Workplace Protection Factors			
					$\frac{N_{2-5}}{cQ}$	$\frac{N_{6-20}}{cQ}$	$\frac{N_{21-30}}{cQ}$	$\frac{N_{2-5}}{cQ}$	$\frac{N_{6-20}}{cQ}$	$\frac{N_{21-30}}{cQ}$	WPF_{2-5}	WPF_{6-20}	WPF_{21-30}	WPF_T
840305	630	740	35.	N	144.	581.	304.	1560.	6191.	2434.	10.8	10.7	8.0	9.9
840305	630	825	30.	N	36.	96.	43.	276.	997.	634.	7.6	10.4	14.1	10.8
840305	630	905	30.	N	3.	(25.)	7.	49.	214.	120.	20.1	-	16.4	18.8
840305	630	1000	30.	N	292.	1206.	775.	4796.	19647.	10994.	16.4	16.3	14.2	15.6
840305	630	1122	34.	N	48.	190.	116.	812.	2400.	1959.	16.8	12.6	16.8	14.6
840306	630	810	30.	N	100.	356.	190.	3697.	14982.	8736.	36.8	42.0	45.9	42.4
840306	630	857	30.	N	52.	219.	146.	2804.	11328.	6404.	54.1	51.8	43.8	49.2
840306	630	938	30.	N	118.	444.	277.	3203.	12991.	7491.	27.1	29.2	27.0	28.2
840306	630	1014	26.	N	113.	436.	266.	4027.	16122.	9437.	35.6	36.9	35.5	36.3
840306	630	1128	30.	N	77.	295.	195.	3704.	15420.	8706.	48.2	52.2	44.7	49.1

( ) Invalid data

TABLE 2-7

SUMMARY OF AMS TEST RESULTS FOR SUBJECT C

DATE	CAGE TIME	SAMPLE TIME	SAMPLE PERIOD	FILTER	Normalized Inside Counts			Normalized Outside Counts			Workplace Protection Factors			
					$\frac{N_{2-5}}{\epsilon Q}$	$\frac{N_{6-20}}{\epsilon Q}$	$\frac{N_{21-30}}{\epsilon Q}$	$\frac{N_{2-5}}{\epsilon Q}$	$\frac{N_{6-20}}{\epsilon Q}$	$\frac{N_{21-30}}{\epsilon Q}$	WPF_{2-5}	WPF_{6-20}	WPF_{21-30}	WPF_T
840307	630	808	30.	0	100.	186.	90.	235.	1038.	610.	2.3	5.6	6.8	5.0
840307	630	905	30.	0	12.	41.	45.	89.	266.	143.	7.1	6.4	3.2	5.0
840307	630	1010	30.	0	31.	83.	67.	378.	1622.	955.	12.2	19.5	14.2	16.3
840307	630	1135	28.	0	90.	267.	227.	114.	392.	313.	1.3	1.5	1.4	1.4

TABLE 2-8

SUMMARY OF AMS TEST RESULTS FOR SUBJECT D

DATE	CAGE TIME	SAMPLE TIME	SAMPLE PERIOD	FILTER	Normalized Inside Counts $\frac{N_{2-5}}{\epsilon Q}$	Normalized Inside Counts $\frac{N_{6-20}}{\epsilon Q}$	Normalized Inside Counts $\frac{N_{21-30}}{\epsilon Q}$	Normalized Outside Counts $\frac{N_{2-5}}{\epsilon Q}$	Normalized Outside Counts $\frac{N_{6-20}}{\epsilon Q}$	Normalized Outside Counts $\frac{N_{21-30}}{\epsilon Q}$	Workplace Protection Factors WPF_{2-5}	Workplace Protection Factors WPF_{6-20}	Workplace Protection Factors WPF_{21-30}	Workplace Protection Factors WPF_T
840305	800	930	25.	N	399.	1128.	641.	6904.	20770.	11633.	17.3	18.4	18.1	18.1
840305	800	1005	27.	N	460.	1989.	1398.	6051.	24400.	13952.	13.2	12.3	10.0	11.5
840305	800	1040	26.	N	222.	860.	482.	5095.	21566.	12311.	23.0	25.1	25.5	24.9
840305	800	1138	28.	N	267.	1032.	606.	5413.	22457.	12754.	20.3	21.8	21.0	21.3
840305	800	1220	28.	N	320.	(3850.)	741.	5535.	21429.	12276.	17.3	-	16.6	16.8
840306	800	808	28.	N	506.	2314.	(4388.)	5083.	20932.	12120.	10.1	9.0	-	9.2
840306	800	844	29.	N	622.	(5724.)	1482.	4322.	17889.	10101.	7.0	-	6.8	6.9
840306	800	921	28.	N	588.	4452.	2061.	4250.	18045.	10407.	7.2	4.1	5.0	4.6
840306	800	958	29.	N	324.	(4469.)	875.	5514.	21370.	12183.	17.0	-	13.9	14.8
840306	800	1037	28.	N	307.	1124.	638.	4141.	17162.	9806.	13.5	15.3	15.4	15.0
840306	800	1140	28.	N	330.	(3992.)	788.	4870.	19646.	11132.	14.7	-	14.1	14.3
840306	800	1217	29.	N	272.	1462.	719.	5484.	21915.	12651.	20.2	15.0	17.6	16.3

( ) Invalid data

TABLE 2-9

SUMMARY OF AMS TEST RESULTS FOR SUBJECT D

DATE	CAGE TIME	SAMPLE TIME	SAMPLE PERIOD	FILTER	Normalized Inside Counts			Normalized Outside Counts			Workplace Protection Factors			
					$\frac{N_{2-5}}{cQ}$	$\frac{N_{6-20}}{cQ}$	$\frac{N_{21-30}}{cQ}$	$\frac{N_{2-5}}{cQ}$	$\frac{N_{6-20}}{cQ}$	$\frac{N_{21-30}}{cQ}$	WPF_{2-5}	WPF_{6-20}	WPF_{21-30}	WPF_T
840307	800	802	29.	0	560.	(8789.)	1391.	4978.	20490.	11640.	8.9	-	8.4	8.5
840307	800	829	29.	0	567.	3531.	(3731.)	5320.	22867.	12881.	9.7	6.5	-	6.9
840307	800	918	30.	0	632.	6458.	3795.	4887.	22194.	11147.	7.7	3.4	2.9	3.5
840307	800	957	30.	0	1328.	(18908.)	5690.	5167.	20903.	11741.	3.9	-	2.1	2.4
840307	800	1035	30.	0	447.	1615.	983.	5262.	22179.	12787.	11.8	13.7	13.0	13.2
840307	800	1202	30.	0	495.	1972.	1042.	5136.	20963.	11881.	10.4	10.6	11.4	10.8

( ) Invalid data

TABLE 2-10

SUMMARY OF AMS TEST RESULTS FOR SUBJECT E

DATE	CAGE TIME	SAMPLE TIME	SAMPLE PERIOD	FILTER	Normalized Inside Counts			Normalized Outside Counts			Workplace Protection Factors			
					$\frac{N_{2-5}}{cQ}$	$\frac{N_{6-20}}{cQ}$	$\frac{N_{21-30}}{cQ}$	$\frac{N_{2-5}}{cQ}$	$\frac{N_{6-20}}{cQ}$	$\frac{N_{21-30}}{cQ}$	WPF_{2-5}	WPF_{6-20}	WPF_{21-30}	WPF_T
840302	800	840	40.	N	497.	1835.	1077.	5571.	22312.	13067.	11.2	12.2	12.1	12.0
840302	800	922	30.	N	258.	903.	500.	2391.	9710.	5542.	9.3	10.8	11.1	10.6
840302	800	1025	40.	N	150.	592.	341.	4757.	19275.	10986.	31.7	32.6	32.2	32.3
840302	800	1310	30.	N	30.	144.	65.	496.	2022.	1178.	16.6	14.1	18.2	15.5
840302	800	1405	33.	N	181.	652.	389.	157.	636.	370.	.9	1.0	1.0	1.0
840301	800	857	43.	N	211.	1097.	640.	5635.	23219.	13565.	26.8	21.2	21.2	21.8
840301	800	1023	42.	N	358.	1316.	758.	2948.	10358.	5884.	8.2	7.9	7.8	7.9
840301	800	1255	35.	N	(9.)	(34.)	(19.)	2365.	10177.	5608.	(252.0)	(299.2)	(298.8)	(292.0)
840301	800	1408	37.	N	624.	2554.	1450.	7238.	30443.	17395.	11.6	11.9	12.0	11.9

( ) Invalid data

TABLE 2-11

SUMMARY OF AMS TEST RESULTS FOR SUBJECT F

DATE	CAGE TIME	SAMPLE TIME	SAMPLE PERIOD	FILTER	Normalized Inside Counts			Normalized Outside Counts			Workplace Protection Factors			
					$\frac{N_{2-5}}{cQ}$	$\frac{N_{6-20}}{cQ}$	$\frac{N_{21-30}}{cQ}$	$\frac{N_{2-5}}{cQ}$	$\frac{N_{6-20}}{cQ}$	$\frac{N_{21-30}}{cQ}$	WPF_{2-5}	WPF_{6-20}	WPF_{21-30}	WPF_T
840301	730	900	30.	N	195.	714.	414.	2262.	8852.	3707.	11.6	12.4	8.9	11.2
840301	730	933	33.	N	177.	532.	285.	1878.	5743.	3666.	10.6	10.8	12.9	11.3
840301	730	1050	30.	N	196.	791.	402.	1296.	4906.	2760.	6.6	6.2	6.9	6.5
840301	730	1130	30.	N	211.	1214.	501.	1264.	5786.	2916.	6.0	4.8	5.8	5.2
840301	730	1010	30.	N	143.	575.	297.	2164.	8686.	4732.	15.1	15.1	16.0	15.4
840302	730	758	28.	N	-	-	190.	1400.	9103.	3210.	-	-	16.9	16.9
840302	730	826	34.	N	39.	108.	73.	1237.	4615.	2709.	31.5	42.6	37.3	38.8
840302	730	1030	18.	N	30.	132.	92.	1005.	3645.	1964.	33.8	27.6	21.3	26.0
840302	730	1135	29.	N	46.	214.	104.	1225.	5544.	3096.	26.4	25.9	29.9	27.1
840302	730	1235	25.	N	50.	206.	123.	1132.	4522.	2548.	22.6	21.9	21.6	21.9

TABLE 2-12

SUMMARY OF AMS TEST RESULTS FOR SUBJECT F

DATE	CAGE TIME	SAMPLE TIME	SAMPLE PERIOD	FILTER	Normalized Inside Counts $\frac{N_{2-5}}{\epsilon Q}$	$\frac{N_{6-20}}{\epsilon Q}$	$\frac{N_{21-30}}{\epsilon Q}$	Normalized Outside Counts $\frac{N_{2-5}}{\epsilon Q}$	$\frac{N_{6-20}}{\epsilon Q}$	$\frac{N_{21-30}}{\epsilon Q}$	Workplace Protection Factors WPF_{2-5}	WPF_{6-20}	WPF_{21-30}	WPF_T
840312	730	738	31.	0	131.	531.	379.	1205.	5251.	2817.	9.2	9.9	7.4	8.9
840312	730	821	31.	0	140.	592.	304.	1302.	5499.	2954.	9.3	9.3	9.7	9.4
840312	730	907	32.	0	146.	608.	363.	1554.	5758.	3318.	10.6	9.5	9.1	9.5
840312	730	1000	27.	0	310.	1148.	671.	1061.	3856.	2179.	3.4	3.4	3.2	3.3

TABLE 2-13

SUMMARY OF AHS TEST RESULTS FOR SUBJECT G

DATE	CAGE TIME	SAMPLE TIME	SAMPLE PERIOD	FILTER	Normalized Inside Counts			Normalized Outside Counts			Workplace Protection Factors			
					$\frac{N_{2-5}}{\epsilon Q}$	$\frac{N_{6-20}}{\epsilon Q}$	$\frac{N_{21-30}}{\epsilon Q}$	$\frac{N_{2-5}}{\epsilon Q}$	$\frac{N_{6-20}}{\epsilon Q}$	$\frac{N_{21-30}}{\epsilon Q}$	WPF_{2-5}	WPF_{6-20}	WPF_{21-30}	WPF_T
840312	700	736	40.	0	97.	474.	235.	642.	2739.	1515.	6.6	5.8	6.4	6.1
840312	700	815	30.	0	43.	172.	103.	360.	1361.	834.	8.4	7.9	8.1	8.0
840312	700	852	36.	0	71.	270.	148.	390.	1612.	1009.	5.5	6.0	6.8	6.2
840312	700	936	31.	0	38.	156.	81.	361.	1494.	875.	9.6	9.6	10.9	10.0
840312	700	1013	32.	0	142.	567.	333.	532.	2027.	1255.	3.8	3.6	3.8	3.7

TABLE 2-14

SUMMARY OF AHS TEST RESULTS FOR SUBJECT A

CALCULATED RADON DAUGHTER CONCENTRATIONS AND WORKING LEVELS

DATE	SAMPLE TIME	SAMPLE PERIOD	FILTER	$[RaA]_f$ pCi/L	$[RaB]_f$ pCi/L	$[RaC]_f$ pCi/L	WL_f	$[RaA]_o$ pCi/L	$[RaB]_o$ pCi/L	$[RaC]_o$ pCi/L	WL_o
840228	823	30.	N	-5.33	2.90	3.88	.0237	17.64	65.29	57.08	.5621
840228	935	33.	N	-1.92	5.64	4.75	.0443	84.68	82.23	51.98	.6981
840228	1138	37.	N	-	-	-	-	103.15	72.82	42.20	.6332
840228	1225	30.	N	.63	.73	.63	.0067	18.23	27.43	16.73	.2202
840228	1300	30.	N	-	-	-	-	95.00	75.33	53.78	.6804
840227	900	32.	N	4.13	2.66	.30	.0189	-254.62	22.73	56.70	.0643
840227	950	33.	N	-2.07	1.44	1.54	.0109	5.79	18.69	12.32	.1467
840227	1058	30.	N	1.02	.49	.85	.0067	-5.93	15.16	8.71	.1032
840227	1255	27.	N	-.43	1.31	1.18	.0106	13.00	24.45	11.28	.1794

TABLE 2-15

SUMMARY OF AHS TEST RESULTS FOR SUBJECT A

CALCULATED RADON DAUGHTER CONCENTRATIONS AND WORKING LEVELS

DATE	SAMPLE TIME	SAMPLE PERIOD	FILTER	$[RaA]_f$ pCi/L	$[RaB]_f$ pCi/L	$[RaC]_f$ pCi/L	WL_f	$[RaA]_o$ pCi/L	$[RaB]_o$ pCi/L	$[RaC]_o$ pCi/L	WL_o
840229	658	39.	0	21.00	4.79	-2.90	.0314	14.45	5.17	-1.84	.0342
840229	842	30.	0	14.82	15.52	13.21	.1432	-	-	-	-
840229	921	30.	0	17.13	17.99	10.85	.1493	50.28	62.01	44.11	.5307
840229	1000	30.	0	3.81	15.27	10.57	.1208	97.53	65.49	39.95	.5816
840229	1040	30.	0	22.50	13.41	6.27	.1145	47.17	52.81	36.75	.4535

TABLE 2-16

SUMMARY OF AHS TEST RESULTS FOR SUBJECT B

CALCULATED RADON DAUGHTER CONCENTRATIONS AND WORKING LEVELS

DATE	SAMPLE TIME	SAMPLE PERIOD	FILTER	$[RaA]_i$ pCi/L	$[RaB]_i$ pCi/L	$[RaC]_i$ pCi/L	WL_i	$[RaA]_o$ pCi/L	$[RaB]_o$ pCi/L	$[RaC]_o$ pCi/L	WL_o
840227	850	39.	N	-	-	-	-	-	-	-	-
840227	929	31.	N	-	-	-	-	9.89	2.91	.91	.0283
840227	1007	28.	N	-	-	-	-	-9.34	4.69	1.87	.0212
840227	1140	27.	N	-1.34	.07	.25	-.0001	-7.23	4.17	2.98	.0248
840227	1215	25.	N	-	-	-		-	-	-	
840227	1247	25.	N	-.42	-.07	.38	.0007	-3.21	3.88	1.85	.0232
840228	815	30.	N	4.38	.58	-.14	.0069	25.75	9.43	4.01	.0893
840228	855	30.	N	-1.42	.21	.39	.0010	5.06	8.76	8.79	.0824
840228	932	33.	N	.69	.10	.16	.0018	-2.26	4.30	3.08	.0309
840228	1015	30.	N	1.41	.05	.03	.0018	5.61	10.35	7.21	.0851
840228	1042	30.	N	-.65	.49	.66	.0043	38.61	8.89	5.39	.1059

TABLE 2-17

SUMMARY OF AHS TEST RESULTS FOR SUBJECT B

CALCULATED RADON DAUGHTER CONCENTRATIONS AND WORKING LEVELS

DATE	SAMPLE TIME	SAMPLE PERIOD	FILTER	$[RaA]_i$ pCi/L	$[RaB]_i$ pCi/L	$[RaC]_i$ pCi/L	WL_i	$[RaA]_o$ pCi/L	$[RaB]_o$ pCi/L	$[RaC]_o$ pCi/L	WL_o
840229	800	45.	0	19.91	4.11	-2.08	.0336	20.06	16.67	9.10	.1391
840229	850	30.	0	-	-	-	-	9.35	13.00	7.84	.1048
840229	930	30.	0	-	-	-	-	8.31	12.79	9.56	.1090
840229	1010	30.	0	-	-	-	-	37.22	14.10	4.07	.1250
840229	1205	30.	0	-	-	-	-	3.30	12.61	10.67	.1071
840229	1305	60.	0	39.75	.77	-3.22	.0329	-62.06	5.75	31.90	.0842

TABLE 2-18

SUMMARY OF AHS TEST RESULTS FOR SUBJECT C

CALCULATED RADON DAUGHTER CONCENTRATIONS AND WORKING LEVELS

DATE	SAMPLE TIME	SAMPLE PERIOD	FILTER	$[RaA]_f$ pCi/L	$[RaB]_f$ pCi/L	$[RaC]_f$ pCi/L	WL_f	$[RaA]_o$ pCi/L	$[RaB]_o$ pCi/L	$[RaC]_o$ pCi/L	WL_o
840305	740	35.	N	.35	.92	1.10	.0092	-55.71	3.21	27.36	.0609
840305	825	30.	N	1.78	-.06	.21	.0023	14.05	2.44	-.32	.0257
840305	905	30.	N	-	-	-	-	-.02	.51	.35	.0039
840305	1000	30.	N	10.58	3.61	-.18	.0285	51.83	42.63	29.39	.3792
840305	1122	34.	N	1.62	.43	.04	.0040	92.85	6.40	-10.78	.0879
840306	810	30.	N	2.31	.50	.60	.0073	73.89	35.34	14.97	.3111
840306	857	30.	N	2.17	.73	-.14	.0054	41.60	24.66	15.29	.2249
840306	938	30.	N	5.06	1.10	.01	.0108	56.97	29.87	14.70	.2650
840306	1014	26.	N	3.99	1.22	.25	.0112	90.72	42.72	18.84	.3803
840306	1128	30.	N	3.88	.86	-.19	.0076	36.53	35.06	22.01	.2975

TABLE 2-19

SUMMARY OF AHS TEST RESULTS FOR SUBJECT C

CALCULATED RADON DAUGHTER CONCENTRATIONS AND WORKING LEVELS

DATE	SAMPLE TIME	SAMPLE PERIOD	FILTER	$[RaA]_f$ pCi/L	$[RaB]_f$ pCi/L	$[RaC]_f$ pCi/L	WL_f	$[RaA]_o$ pCi/L	$[RaB]_o$ pCi/L	$[RaC]_o$ pCi/L	WL_o
840307	808	30.	0	8.69	-.51	.10	.0067	1.81	2.79	1.13	.0203
840307	905	30.	0	2.23	.27	-.40	.0022	4.26	.18	.32	.0065
840307	1010	30.	0	3.65	.23	-.30	.0035	4.98	4.22	1.63	.0326
840307	1135	28.	0	11.07	1.09	-1.39	.0117	11.50	1.63	-1.46	.0147

TABLE 2-20

SUMMARY OF AHS TEST RESULTS FOR SUBJECT D

CALCULATED RADON DAUGHTER CONCENTRATIONS AND WORKING LEVELS

DATE	SAMPLE TIME	SAMPLE PERIOD	FILTER	$[RaA]_i$ pCi/L	$[RaB]_i$ pCi/L	$[RaC]_i$ pCi/L	WL_i	$[RaA]_o$ pCi/L	$[RaB]_o$ pCi/L	$[RaC]_o$ pCi/L	WL_o
840305	930	25.	N	24.85	1.31	.70	.0348	368.71	27.84	20.61	.5981
840305	1005	27.	N	23.19	8.19	-2.32	.0568	104.11	59.46	34.12	.5360
840305	1040	26.	N	4.39	1.94	1.38	.0195	47.17	57.43	34.45	.4683
840305	1138	28.	N	7.61	2.45	.94	.0238	62.35	54.32	33.13	.4632
840305	1220	28.	N	-	-	-	-	130.61	47.84	26.16	.4747
840306	808	28.	N	-	-	-	-	82.52	52.57	25.80	.4478
840306	844	29.	N	-	-	-	-	46.70	41.37	26.39	.3563
840306	921	28.	N	-106.68	12.56	20.45	.0300	43.44	46.71	24.26	.3741
840306	958	29.	N	-	-	-	-	124.60	45.69	26.08	.4573
840306	1037	28.	N	9.22	2.22	1.34	.0258	52.86	42.08	24.08	.3577
840306	1140	28.	N	-	-	-	-	75.30	45.40	28.32	.4134
840306	1217	29.	N	-18.33	3.43	5.02	.0174	111.06	50.83	25.03	.4656

TABLE 2-21

SUMMARY OF AMS TEST RESULTS FOR SUBJECT D

CALCULATED RADON DAUGHTER CONCENTRATIONS AND WORKING LEVELS

DATE	SAMPLE TIME	SAMPLE PERIOD	FILTER	$[RaA]_f$ pCi/L	$[RaB]_f$ pCi/L	$[RaC]_f$ pCi/L	WL_f	$[RaA]_o$ pCi/L	$[RaB]_o$ pCi/L	$[RaC]_o$ pCi/L	WL_o
840307	802	29.	0	-	-	-	-	63.77	47.72	28.53	.4141
840307	839	29.	0	-	-	-	-	56.45	52.65	34.39	.4534
840307	918	30.	0	-129.48	29.18	14.10	.0671	-131.05	43.44	63.35	.3215
840307	957	30.	0	-	-	-	-	69.64	44.87	29.81	.4105
840307	1035	30.	0	19.42	3.51	.37	.0392	62.10	53.91	26.90	.4376
840307	1202	30.	0	2.81	3.49	4.06	.0357	70.33	46.68	28.15	.4141

TABLE 2-22

SUMMARY OF AHS TEST RESULTS FOR SUBJECT E

CALCULATED RADON DAUGHTER CONCENTRATIONS AND WORKING LEVELS

DATE	SAMPLE TIME	SAMPLE PERIOD	FILTER	$[RaA]_i$ pCi/L	$[RaB]_i$ pCi/L	$[RaC]_i$ pCi/L	WL_i	$[RaA]_o$ pCi/L	$[RaB]_o$ pCi/L	$[RaC]_o$ pCi/L	WL_o
840302	840	40.	N	17.09	2.79	.61	.0341	125.38	41.14	11.46	.3806
840302	922	30.	N	8.45	1.37	1.13	.0199	37.72	21.81	12.16	.1948
840302	1025	40.	N	3.31	1.02	.39	.0100	75.30	34.45	16.08	.3123
840302	1310	30.	N	-1.72	.23	.58	.0016	9.39	4.80	2.07	.0417
840302	1405	33.	N	7.36	1.19	.22	.0145	2.99	1.38	.56	.0122
840301	857	43.	N	-4.75	2.89	.97	.0134	100.33	42.81	11.66	.3640
840301	1023	42.	N	11.46	1.80	.61	.0232	105.50	11.64	5.43	.1880
840301	1255	35.	N	.25	.05	.04	.0006	-.25	20.80	15.31	.1633
840301	1408	37.	N	8.44	4.89	2.56	.0431	75.47	62.14	29.97	.5046

TABLE 2-23

SUMMARY OF AMS TEST RESULTS FOR SUBJECT F

CALCULATED RADON DAUGHTER CONCENTRATIONS AND WORKING LEVELS

DATE	SAMPLE TIME	SAMPLE PERIOD	FILTER	$[RaA]_f$ pCi/L	$[RaB]_f$ pCi/L	$[RaC]_f$ pCi/L	WL_f	$[RaA]_o$ pCi/L	$[RaB]_o$ pCi/L	$[RaC]_o$ pCi/L	WL_o
840301	900	30.	N	6.48	1.40	.60	.0160	-56.72	5.75	37.46	.1105
840301	933	33.	N	8.48	.27	.57	.0123	131.40	8.45	-3.13	.1591
840301	1050	30.	N	-.65	1.29	1.98	.0132	30.78	9.39	6.20	.1025
840301	1130	30.	N	-25.23	2.14	6.12	.0077	-35.10	11.56	16.40	.0836
840301	1010	30.	N	.04	.97	1.34	.0099	20.31	16.99	15.20	.1638
840302	754	28.	N	-	-	-	-	-263.11	12.34	60.66	.0176
840302	826	34.	N	3.41	.12	-.20	.0034	40.81	8.52	2.58	.0949
840302	1030	18.	N	1.36	.80	-.06	.0052	23.64	9.33	10.06	.1092
840302	1135	29.	N	-1.71	.40	.72	.0029	-7.67	14.08	9.88	.1093
840302	1235	25.	N	1.08	.61	.23	.0050	25.98	12.39	5.56	.1197

TABLE 2-24

SUMMARY OF AHS TEST RESULTS FOR SUBJECT F

CALCULATED RADON DAUGHTER CONCENTRATIONS AND WORKING LEVELS

DATE	SAMPLE TIME	SAMPLE PERIOD	FILTER	$[RaA]_f$ pC1/L	$[RaB]_f$ pC1/L	$[RaC]_f$ pC1/L	WL_f	$[RaA]_o$ pC1/L	$[RaB]_o$ pC1/L	$[RaC]_o$ pC1/L	WL_o
840312	738	31.	0	8.11	1.85	-.88	.0144	-8.60	11.09	10.63	.0870
840312	821	31.	0	-1.37	1.07	1.44	.0094	-1.97	11.09	10.71	.0941
840312	907	32.	0	2.97	1.49	.41	.0122	47.86	10.60	4.85	.1212
840312	1000	27.	0	10.29	2.61	1.09	.0279	32.13	7.68	5.00	.0907

TABLE 2-25

SUMMARY OF AHS TEST RESULTS FOR SUBJECT G

CALCULATED RADON DAUGHTER CONCENTRATIONS AND WORKING LEVELS

DATE	SAMPLE TIME	SAMPLE PERIOD	FILTER	$[RaA]_i$ pCi/L	$[RaB]_i$ pCi/L	$[RaC]_i$ pCi/L	WL_i	$[RaA]_o$ pCi/L	$[RaB]_o$ pCi/L	$[RaC]_o$ pCi/L	WL_o
840312	736	40.	0	-4.36	.94	1.22	.0048	1.39	5.12	3.41	.0401
840312	815	30.	0	1.12	.43	.11	.0037	14.06	3.25	.33	.0322
840312	852	36.	0	1.28	.42	.34	.0047	12.10	3.91	-.12	.0319
840312	936	31.	0	-.18	.27	.36	.0026	6.37	3.58	1.40	.0299
840312	1013	32.	0	3.27	1.26	.45	.0114	21.13	4.71	.11	.0461

Table 2-26: Test Subject Work Activities (AH-5 Field Tests)

Subject	Date	Activities During Sampling Periods
A	1984 02 27	Inspecting and repairing water lines in underground uranium leaching areas. Generally worked in different areas in every sample period.
	1984 02 28	Same activities as on 1984 02 27 though work was performed in a different area.
	1984 02 29	Travel from cage to workshop then work area to work on pump repairs. Last three samples obtained in same area.
B	1984 02 27	Installing electrical cable. Working in the same general area but frequently to either side of a ventilation bulkhead during the measurement periods.
	1984 02 28	Installing electrical cable. Very little travel outside of the immediate area.
	1984 02 29	Installing electrical cable in different areas. Sampling performed during both stationary work as well as while travelling to and from work areas.
C	1984 03 05	Conveyor belt inspection and operation. Samples were obtained while the subject worked in the same general area.
	1984 03 06	Conveyor belt operation and operation of ore transfer chutes. Subject moved to different areas during most of the sample periods.
	1984 03 07	Conveyor belt operation and operation of ore transfer chutes. Same general area.
D	1984 03 05	Sampling during drilling activities while in the same general area.
	1984 03 06	As on 1984 03 05.
	1984 03 07	As on 1984 03 05.
E	1984 03 02	Servicing and repair of pump during the first part of shift; repairing water lines during the latter part of the shift.
F	1984 03 01	Scoop tram operation.
	1984 03 02	Scoop tram operation.
	1984 03 13	Scoop tram operation.
G	1984 03 12	Scoop tram operation.

Table 2-27: Respirator Air Exit Velocities

SUBJECT	DATE	FILTER	AIR VELOCITIES (m/s) START OF SHIFT V_E	V_R	V_L	END OF SHIFT V_E	V_R	V_L
A	1984.02.29	Old	0.5	0.25	0.5	-	-	-
B	1984.02.29	Old	1.1	0.2	0.5	1.0	0.05	0.2
C	1984.03.05	New	1.0	0.9	0.75	1.1	1.0	0.8
C	1984.03.06	New	1.1	0.65	0.9	-	-	-
C	1984.03.07	Old	1.0	0.8	0.9	-	-	-
D	1984.03.05	New	-	-	-	1.0	0.4	0.25
D	1984.03.06	New	1.2	0.75	0.25	1.2	0.75	0.5
D	1984.03.07	Old	1.3	0.6	0.25	1.1	0.65	0.5
E	1984.03.02	New	-	-	-	0.6	0.3	0.1
F	1984.03.01	New	0.5	0.2	0.5	0.9	0.15	0.2
F	1984.03.02	New	0.9	0.25	0.7	1.0	0.5	0.75
F	1984.03.13	Old	0.9	0.9	1.0	-	-	-
G	1984.03.12	Old	0.5	0.6	0.75	0.45	1.0	0.7

Table 2-28: Workplace Protection Factor Distributions

SET/SUBSET	TYPE OF DISTRIBUTION	$\overline{WPF}$	σ	KURTOSIS	SKEWNESS	K - S TEST Z	K - S TEST P(Z)
NEW	(normal)	(21.4)	(14.0)	(1.9)	(1.5)	1.52	.020
NEW	lognormal	17.8	1.84	-0.080	0.065	0.61	.85
OLD	normal	6.2	3.4	0.21	0.82	0.94	.34
OLD	lognormal	5.3	1.79	0.71	-0.54	0.60	.87

Table 2-29: Summary Of WPF Analysis Of Variance

DATA	APPROACH	EFFECTS SIGNIFICANT AT .01	EFFECTS SIGNIFICANT AT .05	NO EFFECT (.05)
ALL	Experimental	Filter Subject Covariates (log)	Covariates (WPF)	V_E T T_C C_p
ALL	Experimental (T_C and Cp discarded)	Filter Covariates (log)	Subject (WPF) Covariates (WPF) V_E	Subject (log) T
ALL	Regression	Filter Subject V_E C_p		T_C T
ALL	Hierarchical (Filt, Sub, V_E, T_C C_p, T)	Filter V_E (WPF) C_p	V_E (log)	Subject T_C T
OLD	Regression		C_p (log)	Subject, C_p (WPF), T_C, T
OLD	Hierarchical (Subject, T_C, C_p, T)			Subject, C_p, C_p, T
OLD	Oneway			Subject
NEW	Experimental (WPF)	Subject		V_E, C_p, T_C, T
NEW	Experimental	Days		T
NEW	Experimental	Subject		T
NEW	Regression	Days		T_C, C_p, T
NEW	Hierarchical (Days, T_C, C_p, T)	Days		T_C, C_p, T
NEW	Oneway	Days		

Table 2-30: Regression Coefficients of Transformed and Untransformed WPFs With V_E (sm^{-1})

ANOVA APPROACH	UNTRANSFORMED WPF $\frac{d\ WPF}{dV_E}$	TRANSFORMED WPF $\frac{d\ Log_{10}\ WPF}{dV_E}$
Experimental	9.33	0.32 (9)*
Regression	40.8	0.94 (26)
Hierarchical	40.8	0.95 (26)

* Values in parenthesis are the equivalent d_{WPF}/dV_E.

Table 3-1: Months Of Experience With Respirator (Question 3)

MONTHS	ABSOLUTE FREQUENCY	RELATIVE FREQUENCY %	AJUSTED FREQUENCY %	CUMULATIVE FREQUENCY %
1	8	3.9	4.0	4.0
2	4	1.9	2.0	6.0
3	4	1.9	2.0	8.0
4	1	0.5	0.5	8.5
5	1	0.5	0.5	9.0
6	7	3.4	3.5	12.6
7	1	0.5	0.5	13.1
8	2	1.0	1.0	14.1
12	17	8.2	8.5	22.5
15	1	0.5	0.5	23.1
18	8	3.9	4.0	27.1
24	49	23.7	24.6	51.8
30	8	3.9	4.0	55.8
36	33	15.9	16.6	72.4
42	2	1.0	1.0	73.4
48	22	10.6	11.1	84.4
54	5	2.4	2.5	86.9
60	16	7.7	8.0	95.0
66	1	0.5	0.5	95.0
72	6	2.9	3.0	98.5
84	3	1.4	1.5	100.0
No answer given	8	3.9		
Total	207	100.0	100.0	

Table 3-2: Survey Response By Job Classification (Question 1)

	ABSOLUTE FREQUENCY	RELATIVE FREQUENCY %	ADJUSTED FREQUENCY %
Truck	22	10.6	10.9
Miner	10	4.8	5.0
Heavy Equipment Operator	20	9.7	9.9
Scoop	38	18.4	18.8
Driller	11	5.3	5.4
Haulage	9	4.3	4.5
Belt	17	8.2	8.4
Labour	5	2.4	2.5
Rock Breaker	9	4.3	4.5
Leaching	4	1.9	2.0
Tradesmen	20	9.7	9.9
Bolter	4	1.9	2.0
Equipment Operator	5	2.4	2.5
Operator	5	2.4	2.5
Other-Special Vehicle	4	1.9	2.0
Other-Special Equipment	13	6.3	6.4
Other	6	2.9	3.0
Blank	5	2.4	-
Total	207	100.4	100.0

Table 3-3: Rating of Comfort (Question 4)

	ABSOLUTE FREQUENCY	RELATIVE FREQUENCY %	ADJUSTED FREQUENCY %	CUMULATIVE FREQUENCY %
Always	66	31.9	32.7	32.7
Most of the Time	102	49.3	50.5	83.2
Sometimes	24	11.6	11.9	95.0
Never	10	4.8	5.0	100.0
No Answer Given	5	2.4	-	
Total	207	100.0	100.0	

Table 3-4: Visibility Rating (Question 5)

	ABSOLUTE FREQUENCY	RELATIVE FREQUENCY %	ADJUSTED FREQUENCY %	CUMULATIVE FREQUENCY %
Good	122	58.9	59.5	59.5
Usually Good	74	35.7	36.1	95.6
Sometimes Good	6	2.9	2.9	98.5
Poor	3	1.4	1.5	100.1
No Answer Given	2	1.0	-	
Total	207	100.0	100.0	

Table 3-5: Work Activities Where Airstream Problems Encountered

ACTIVITY	ABSOLUTE FREQUENCY	ADJUSTED FREQUENCY (%)	RELATIVE FREQUENCY (%)
Strenuous Work	84	57.5	40.6
Confined Areas	11	7.5	5.3
Bending	32	21.9	15.4
Communicating	8	5.4	3.9
Spraying Water	8	5.4	3.9
Turning Head	1	0.7	0.5
Dusty Areas	2	1.4	1.0
No Comments	61	-	29.5
	207		

Table 3-6: Respirator Failed In Use (Question 8)

	ABSOLUTE FREQUENCY	RELATIVE FREQUENCY %	ADJUSTED FREQUENCY %
No	89	43.0	43.8
Yes	114	55.1	56.2
No Answer Given	4	1.9	-
Total	207	100.0	100.0
OCCURRENCES OF RESPIRATOR FAILURE			
1-times	9	4.3	20.5
2-times	18	8.7	40.9
3-times	11	5.3	25.0
4-times	2	1.0	4.5
5-times	2	1.0	4.5
6-times	2	1.0	4.5
Often	12	5.8	-
Not Very Often	25	12.1	-
No Answer Given	126	60.9	-
Total	207	100.0	100.0
SERVICE SATISFACTORY AFTER FAILURE			
No	10	4.8	9.9
Yes	91	44.0	90.1
Not Applicable	89	43.0	-
No Answer Given	17	6.2	-
Total	207	100.0	100.0

Table 3-7: Types Of Respirator Failures

FAILURE	ABSOLUTE FREQUENCY	RELATIVE FREQUENCY (%)
Motor/Fan	58	48.3
Battery	39	32.5
Wiring/Connectors	17	14.1
Visor	3	2.5
Screen Cover	1	<1
Filter	1	<1
Light Bracket	1	<1
	120	

Table 3-8: Changes In Airflow Noticed During Shift (Question 9)

	ABSOLUTE FREQUENCY	RELATIVE FREQUENCY %	ADJUSTED FREQUENCY %	CUMULATIVE FREQUENCY %
Never	70	33.8	34.5	34.5
Sometimes	94	45.4	46.3	80.8
Most of the Time	15	7.2	7.4	88.2
Always	24	11.5	11.8	100.0
No Answer Given	4	1.9	-	
Total	207	100.0	100.0	
CHANGES IN CAP LAMP INTENSITY NOTICED DURING SHIFT				
No	28	13.5	23.3	
Yes	92	44.4	76.7	
Not Applicable	70	33.5	-	
No Answer Given	17	8.2	-	
	207	100.0	100.0	

Table 3-9: Lifts Visor When Talking (Question 6)

	ABSOLUTE FREQUENCY	RELATIVE FREQUENCY %	ADJUSTED FREQUENCY %	CUMULATIVE FREQUENCY %
Sometimes	41	19.3	19.9	19.9
Most of the Time	63	30.4	30.6	50.5
Always	102	49.3	49.5	100.0
No Answer Given	1	0.5	-	
Total	207	100.0	100.0	

Table 3-10: Travels With Visor Up or Down (Question 10)

	ABSOLUTE FREQUENCY	RELATIVE FREQUENCY %	ADJUSTED FREQUENCY %	CUMULATIVE FREQUENCY %
Up	95	45.9	47.0	47.0
Down	107	51.7	53.0	100.0
No Answer Given	5	2.4	-	
Total	207	100.0	100.0	

Table 3-11: Hours Of Shift With Visor Down (Question 11)

HOURS	ABSOLUTE FREQUENCY	RELATIVE FREQUENCY %	ADJUSTED FREQUENCY %	CUMULATIVE FREQUENCY %
¼	3	1.4	1.5	1.5
1	3	1.4	1.5	2.9
2	3	1.4	1.5	4.4
2½	2	1.0	1.0	5.4
3	2	1.0	1.0	6.4
3½	1	0.5	0.5	6.9
4	9	4.3	4.4	11.3
4½	5	2.4	2.5	13.7
5	16	7.7	7.8	21.6
5½	12	5.8	5.9	27.5
6	46	22.2	22.5	50.0
6½	34	16.4	16.7	66.7
7	38	18.4	18.6	85.3
7½	30	14.5	14.7	100.0
No Answer Given	3	1.4	-	
Total	207	100.0	100.0	

Table 3-12: Summary of Comments On The Use Of The Airstream AH-5* PAPR

Comment*	Frequency	Comment/Corrective Action
Improvements needed to lamp holder	7	Maintenance
Visor won't stay in raised position	9	Loose visor or worn helmet shell
Too cool when wearing	12	Use of a liner
Too heavy	30	
Too tight with glasses	8	Use of respirator glasses
More comfortable headband required	2	
Visor tends to raise	4	Replace worn parts (maintenance)
Too hot	8	
Electrical connection disconnects from battery	3	Maintenance
Fogging	7	Work activity related
Better direction of air (to face not top of head)	5	
Better seal between helmet and visor (shield gets dusty)	6	
Ear muffs needed	1	Option is available on some airstream models
Chin strap required	2	Option is available
Better service required	7	Training/retraining
Better filters/battery/fan	25	
Like eye protection provided	6	
Generally like respirator	34	
Generally dislike respirator	1	
Total number of miners responding	116	

*Many multiple responses

Table 4-1: Summary Of Start Of Shift/End Of Shift AH-3 Peripheral Air Velocities (Subject A)

DATE	AIR VELOCITIES (m/s)		
	V_E	V_R	V_L
1984 March 08			
Start of Shift	1.0-1.45	2.9	4.0
End of Shift	0.9	1.9	1.7
1984 March 09			
Start of Shift	1.0	2.6	2.6
End of Shift	1.6	1.6	1.6

TABLE 4-2

SUMMARY OF AM3 TEST RESULTS FOR SUBJECT A

DATE	CAGE TIME	SAMPLE TIME	SAMPLE PERIOD	FILTER	Normalized Inside Counts $\frac{N}{\epsilon Q}$ 2-5	Normalized Inside Counts $\frac{N}{\epsilon Q}$ 6-20	Normalized Inside Counts $\frac{N}{\epsilon Q}$ 21-30	Normalized Outside Counts $\frac{N}{\epsilon Q}$ 2-5	Normalized Outside Counts $\frac{N}{\epsilon Q}$ 6-20	Normalized Outside Counts $\frac{N}{\epsilon Q}$ 21-30	Workplace Protection Factors WPF_{2-5}	WPF_{6-20}	WPF_{21-30}	WPF_T
840309	800	1233	31.	N	772.	2672.	1554.	4607.	18053.	9890.	6.0	6.8	6.4	6.5
840309	800	852	28.	N	-	-	-	-	-	-	-	-	-	-
840309	800	923 *	28.	N	(43.)	14204.	8062.	5852.	23928.	14203.	-	1.7	1.8	1.*
840309	800	957	30.	N	495.	2122.	1367.	5378.	22631.	12714.	10.9	10.6	9.3	10.2
840309	800	1042	38.	N	104.	136.	(31.)	8530.	35061.	19808.	81.8	278.7	-	189.5
840308	800	920	30.	N	16.	69.	38.	6714.	26794.	15208.	417.5	386.8	261.6	339.5
840308	800	958	30.	N	79.	238.	140.	9054.	37835.	21163.	115.3	158.8	150.8	14*.9
840308	800	1035	27.	N	44.	106.	59.	8020.	34946.	18998.	181.0	331.1	324.0	297.2
840308	800	1114	31.	N	76.	306.	192.	8763.	36489.	20187.	115.1	119.3	105.3	114.1

( ) Invalid data

TABLE 4-3

SUMMARY OF AH3 TEST RESULTS FOR SUBJECT A

CALCULATED RADON DAUGHTER CONCENTRATIONS AND WORKING LEVELS

DATE	SAMPLE TIME	SAMPLE PERIOD	FILTER	$[RaA]_i$ pCi/L	$[RaB]_i$ pCi/L	$[RaC]_i$ pCi/L	WL_i	$[RaA]_o$ pCi/L	$[RaB]_o$ pCi/L	$[RaC]_o$ pCi/L	WL_o
840309	1233	31.	N	32.05	4.48	1.66	.0619	65.14	33.37	28.54	.3428
840309	852	28.	N	-	-	-	-	-	-	-	
840309	923	28.	N	-	-	-	-	128.67	63.19	21.97	.5350
840309	957	30.	N	15.70	6.67	-.25	.0491	55.19	51.62	31.13	.4347
840309	1042	30.	N	-	-	-	-	102.41	65.74	36.00	.5731
840308	920	30.	N	1.55	.35	-.28	.0023	117.06	57.74	34.26	.5412
840308	958	30.	N	4.65	.30	.04	.0064	68.34	84.59	58.32	.7168
840308	1035	27.	N	3.40	-.01	.02	.0033	-38.03	83.09	75.13	.6623
840308	1114	31.	N	2.66	.02	.02	.0069	53.62	77.17	58.37	.6642

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APPENDIX A

TRANSFORMATION OF NORMALIZED COUNTS

Determining radon daughter concentrations and the subsequent evaluation of WL's normally follows several standard sampling and counting protocols, all based on the Tsivoglou method. Because of the desire to use extended sampling periods and the practical difficulties in adhering to these strict protocols, the coefficients to Tsivoglou's equations, for each case where the sample period or count interval differed from standard practice, were evaluated.

The decay and buildup of radon daughter activity on a filter after sampling can be described using the following generalized formulation:

$$N\alpha\ (t_o, T_1 \rightarrow T_2) = [(k_{11}f_A + k_{12}f_B + k_{13}f_C)\ RaA + (k_{22}f_B + k_{22}f_C)\ RaB + k_{33}f_C\ RaC]\upsilon\varepsilon Q \qquad (A\text{-}1)$$

where $N\alpha$ = alpha counts measured on filter during $T_1 \rightarrow T_2$

t_o = sampling period (min)

ε = detector efficiency

Q = sample flow rate in L/min

υ = filter efficiency (≈ 1)

RaA, RaB, RaC = radon daughter concentrations in pCi/L

$$f_i = \left(1 - e^{-t_o/T_i}\right)\left(e^{-T_1/T_i} - e^{-T_2/T_i}\right) \qquad (A\text{-}2)$$

i = A, B, C, representing RaA, RaB, RaC

T_i = mean lifetime

T_1, T_2 = count interval times (from completion of sampling) and the constants $k_{ij}; i,j = 1, 2, 3$ are

$$K = \left[k_{ij}\right] = \begin{bmatrix} 43.99 & 1608 & -911.4 \\ 0 & 12527 & -6768 \\ 0 & 0 & 1793 \end{bmatrix}$$

With counts made in three different time intervals $T_1 \rightarrow T_2$, $T_3 \rightarrow T_4$ and $T_5 \rightarrow T_6$ three sets of equations can be generated.

$$\vec{N\alpha} = F\,\vec{K}\,\vec{C}\,\varepsilon Q \qquad (A\text{-}3)$$

F; $[f_{ij}]$ with elements given in A-2, i = A, B, C; J = $T_1 \rightarrow T_2$, $T_3 \rightarrow T_4$, $T_5 \rightarrow T_6$

K; $[k_{ij}]$ with elements previously described. $\tilde{K}$ denotes the transpose.

$\vec{C}$; $[C_{ij}]$ the concentration vector: j = RaA, RaB, RaC

$\vec{N\alpha}$; $[n_{\alpha ij}]$ gross alpha count vector; j = $T_1 \rightarrow T_2$, $T_3 \rightarrow T_4$, $T_5 \rightarrow T_6$

Solving equation A-3 for the concentration vector the coefficients to Tsivoglous equations become

$$[\psi] = [F\tilde{K}]^{-1}$$

and

$$\vec{C} = [F\tilde{K}]^{-1} \vec{N\alpha} \cdot \frac{1}{\varepsilon Q} \qquad \text{(A-4)}$$

If the alpha energy released by the decay of RaA, RaB and RaC in equilibrium with 100 pCi of radon is denoted by $\vec{E}_j$, j = RaA, RaB, RaC then we can write an equation for working levels in terms of integrated counts $\vec{N\alpha}$ made in the three count intervals $T_1 \rightarrow T_2$, $T_3 \rightarrow T_4$ and $T_5 \rightarrow T_6$

$$WL = \frac{1}{\varepsilon Q \; 1.3 \times 10^{-5}} \left[N\alpha(T_1 \rightarrow T_2) \Sigma \psi j_1 Ej + N\alpha(T_3 \rightarrow T_4) \Sigma \psi j_2 Ej + N\alpha(T_4 \rightarrow T_5) \Sigma \psi j_3 E_j \right] \qquad \text{(A-5)}$$

Computations for Tsivoglous' coefficients and WL for various sampling and counting intervals used during the field testing of the respirators are given in Tables A 1 and A 2.

TABLE A1

COEFFICIENTS TO TSIVOGLOU'S EQUATIONS

SAMPLE PERIOD	ϕ_{11}	ϕ_{12}	ϕ_{13}	ϕ_{21}	ϕ_{22}	ϕ_{23}	ϕ_{31}	ϕ_{32}	ϕ_{33}
18.	.11668	-.05663	.05354	-.00751	-.00287	.01237	-.00789	.01283	-.01632
24.	.11522	-.05593	.05287	-.00878	-.00098	.00870	-.00654	.01103	-.01453
25.	.11512	-.05588	.05283	-.00894	-.00075	.00826	-.00639	.01082	-.01433
26.	.11504	-.05584	.05279	-.00909	-.00054	.00785	-.00625	.01063	-.01415
27.	.11497	-.05581	.05276	-.00923	-.00034	.00748	-.00612	.01046	-.01399
28.	.11492	-.05578	.05274	-.00936	-.00016	.00713	-.00600	.01030	-.01384
29.	.11488	-.05576	.05272	-.00948	.00001	.00681	-.00589	.01016	-.01371
30.	.11485	-.05575	.05271	-.00959	.00017	.00651	-.00579	.01003	-.01359
31.	.11483	-.05573	.05269	-.00970	.00031	.00622	-.00570	.00990	-.01348
32.	.11480	-.05572	.05269	-.00980	.00045	.00596	-.00561	.00979	-.01338
33.	.11479	-.05572	.05268	-.00989	.00058	.00571	-.00553	.00969	-.01329
34.	.11478	-.05571	.05267	-.00998	.00070	.00548	-.00546	.00960	-.01321
35.	.11477	-.05571	.05267	-.01006	.00082	.00527	-.00540	.00951	-.01314
36.	.11476	-.05570	.05266	-.01014	.00092	.00506	-.00534	.00943	-.01307
37.	.11475	-.05570	.05266	-.01022	.00102	.00487	-.00528	.00935	-.01301
38.	.11475	-.05570	.05266	-.01029	.00112	.00469	-.00523	.00928	-.01295
39.	.11474	-.05569	.05266	-.01035	.00121	.00452	-.00518	.00922	-.01291
40.	.11474	-.05569	.05265	-.01042	.00130	.00435	-.00513	.00916	-.01286
41.	.11474	-.05569	.05265	-.01048	.00138	.00420	-.00509	.00911	-.01283
42.	.11473	-.05569	.05265	-.01053	.00145	.00405	-.00505	.00906	-.01279
43.	.11473	-.05569	.05265	-.01059	.00153	.00391	-.00502	.00901	-.01276
44.	.11473	-.05569	.05265	-.01064	.00160	.00378	-.00499	.00897	-.01273
45.	.11473	-.05569	.05265	-.01069	.00166	.00366	-.00495	.00893	-.01271
46.	.11473	-.05569	.05265	-.01073	.00173	.00354	-.00493	.00889	-.01269
47.	.11473	-.05569	.05265	-.01078	.00179	.00342	-.00490	.00886	-.01267
48.	.11473	-.05569	.05265	-.01082	.00184	.00332	-.00488	.00883	-.01265
49.	.11473	-.05569	.05265	-.01086	.00190	.00321	-.00485	.00880	-.01264
60.	.11473	-.05569	.05265	-.01120	.00236	.00233	-.00470	.00860	-.01261

TABLE A2

COEFFICIENTS TO THE TSIVOGLOU WORKING LEVEL EQUATION

SAMPLE PERIOD	$\sum \phi_{j1} E_j$	$\sum \phi_{j2} E_j$	$\sum \phi_{j3} E_j$
18.	6.858133	-3.252760	7.409477
24.	6.480013	-2.791499	5.773421
25.	6.436394	-2.734623	5.573737
26.	6.396166	-2.681503	5.388319
27.	6.358841	-2.631673	5.215544
28.	6.324019	-2.584746	5.054029
29.	6.291367	-2.540390	4.902589
30.	6.260610	-2.498327	4.760202
31.	6.231519	-2.458318	4.625984
32.	6.203900	-2.420160	4.499163
33.	6.177590	-2.383676	4.379066
34.	6.152452	-2.348713	4.265103
35.	6.128369	-2.315139	4.156751
36.	6.105240	-2.282839	4.053550
37.	6.082979	-2.251710	3.955089
38.	6.061512	-2.221663	3.861004
39.	6.040775	-2.192619	3.770967
40.	6.020709	-2.164507	3.684685
41.	6.001267	-2.137265	3.601895
42.	5.982405	-2.110836	3.522358
43.	5.964084	-2.085170	3.445860
44.	5.946270	-2.060221	3.372206
45.	5.928932	-2.035950	3.301217
46.	5.912044	-2.012317	3.232733
47.	5.895580	-1.989291	3.166605
48.	5.879519	-1.966840	3.102698
49.	5.863840	-1.944936	3.040888
60.	5.712351	-1.734032	2.472298

APPENDIX B

RACAL AIRSTREAM AH-5* SURVEY QUESTIONNAIRE

1. WHAT IS YOUR JOB CLASSIFICATION? _____
2. ARE YOU A REGULAR USER OF THE AIRSTREAM ? YES NO
3. HOW LONG HAVE YOU BEEN USING THE AIRSTREAM ? _____

4. DO YOU FIND THE AIRSTREAM COMFORTABLE TO WEAR ?
   1. ALWAYS 2. MOST OF THE TIME 3.SOMETIMES 4. NEVER
   IF YOU ANSWERED 2,3 or 4 WHAT ARE THE CAUSES OF THE DISCOMFORT ?
   _____
   _____

5. HOW DO YOU RATE THE VISIBILITY OF THE AIRSTREAM ?
   1. GOOD 2. USUALLY GOOD 3. SOMETIMES GOOD 4. POOR
   IF YOU ANSWERED 2,3 or 4 WHAT ARE THE CAUSES OF POOR VISIBILITY ?
   _____
   _____

6. HOW OFTEN DO YOU FIND YOU MUST LIFT THE VISOR WHEN TALKING ?
   1. SOMETIMES 2. MOST OF THE TIME 3. ALWAYS

7. DURING WHAT TYPE OF ACTIVITIES DO YOU FIND IT MOST DIFFICULT TO USE THE AIRSTREAM ?
   _____
   _____
   _____

8. HAS YOUR AIRSTREAM EVER FAILED IN USE ? YES NO HOW OFTEN ?_____
   WHAT PART OF THE AIRSTREAM FAILED ?_____
   WAS THE SERVICING AFTER FAILURE SATISFACTORY ? _____

9. DURING A SHIFT DO YOU EVER NOTICE A CHANGE IN THE AIRFLOW OF THE AIRSTREAM ?
   1. NEVER 2. SOMETIMES 3. MOST OF THE TIME 4. ALWAYS
   IF YOU ANSWERED 2,3 or 4 DO YOU KNOW WHEN THE CHANGE OCCURS IN THE AIRFLOW ?
   _____
   DOES THE LIGHT FROM YOUR CAP LAMP CHANGE AT THE SAME TIME ? YES NO

10. WHEN TRAVELLING TO AND FROM THE CAGE AND YOUR WORKPLACE/LUNCHROOM DO YOU WEAR YOUR VISOR UP OR DOWN ? 1. UP 2. DOWN

11. WHEN IN YOUR WORKPLACE HOW MUCH OF THE TIME DO YOU HAVE THE VISOR DOWN ?
    BY APPROXIMATE HOURS (circle one) ¼ 1 1¼ 2 2¼ 3 3¼ 4 4¼ 5 5¼ 6 6¼ 7 7¼

12. DO YOU HAVE ANY COMMENTS ON THE AIRSTREAM RESPIRATOR (use with glasses, beards; too hot or cold; weight; good features, bad features, improvements you want)?
    _____
    _____
    _____
    _____
    _____
    _____